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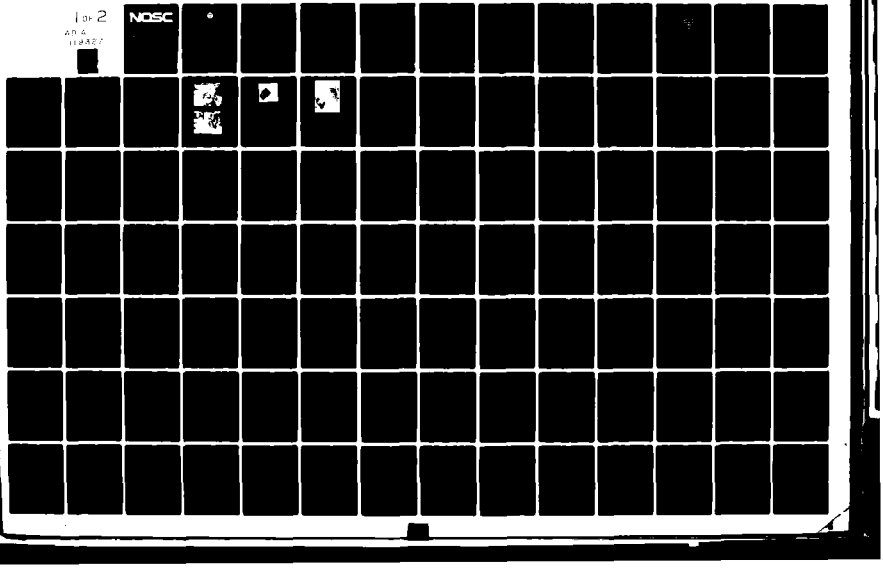

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WORK SYSTEMS PACKAGE AUTOMATIC TOOL INTERCHANGE

Laboratory study shows that automating certain WSP functions is feasible

CE Morrin

10 June 1982

Final Report for Period October 1977 – June 1978

Prepared for
Naval Sea Systems Command
Washington DC 20362

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METRIC CONVERSION

To convert from	to	Multiply by
feet	metres (m)	$\sim 3.05 \times 10^{-1}$
inches	m	2.54×10^{-2}
pounds	kilograms (kg)	$\sim 4.54 \times 10^{-1}$
minutes (angular)	radians (rad)	$\sim 2.91 \times 10^{-4}$
pounds per square inch (psi)	kilopascals (kPa)	~ 6.89
tons (short)	megagrams (Mg)	$\sim 9.07 \times 10^{-1}$
gallons per minute (gpm)	m^3/s	$\sim 6.31 \times 10^{-5}$

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
The Work Systems Package (WSP) is a remotely controlled manipulator with tools and support equipment, developed to interface with manned and unmanned undersea vehicles to perform ocean-floor salvage, recovery, installation, and repair tasks. Since bottom time is limited, risk factors are high, and visibility often is poor or hampered, automation of certain WSP functions would take advantage of the limited available power and reduce the risk factor. Automating the WSP via a computer program allows the WSP accessories (eg, tool box and tools) to be moved out of the prime visibility area of a manned vehicle and helps the operator to perform tasks faster and more efficiently.

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OBJECTIVES

1. Determine the feasibility of automating the tool interchange portion of the tasks performed by the Work Systems Package (WSP) by conducting a laboratory demonstration.

2. In particular, demonstrate that automatic tool interchange can be performed repeatedly without malfunction when the WSP is equipped with fixed-rate position control (hydraulic solenoid valves).

RESULTS

1. The feasibility of automatic tool interchange with the WSP was demonstrated in the laboratory.

2. Equipped with fixed-rate position control, the WSP performed automatic tool interchange repeatedly without malfunction.

RECOMMENDATIONS

1. Incorporate automation into the next work system that is built.

2. Ultimately, conduct in-water tests of the automated work system to verify its feasibility.

CONTENTS

INTRODUCTION

BACKGROUND — THE WORK SYSTEMS PACKAGE

The Work Systems Package (WSP) program, part of the Deep Ocean Technology (DOT) project, was initiated in February 1972 by NOSC in conjunction with the Battelle Memorial Institute (Columbus OH), the Naval Civil Engineering Laboratory (Port Hueneme CA), and the David Taylor Naval Ship Research and Development Center/Annapolis (Annapolis MD), under the direction of the Naval Sea Systems Command.

The WSP is a 5-ton, neutrally buoyant machine assembly designed for ocean-floor salvage, recovery, installation, and repair operations at depths to 20 000 feet. It has restraining and manipulator arms and hands, specially designed tools and a customized tool box, a video monitoring system, required support equipment, and a self-contained power source. It is intended to provide a heavy-duty underwater work capability for the Navy's Cable-Controlled Underwater Recovery Vehicle, CURV III, or Remote Unmanned Work System (RUWS), both cable-controlled submersible vehicles, and the manned vehicles Alvin, Sea Cliff, and Turtle (ref 1). It can also be positioned and controlled without a submersible, from a surface support ship or by divers.

The WSP performs its work functions without having to resurface for tool interchange. The two outer restraining (grabber) arms attach to the work piece to maintain a stable physical orientation with the work object. The manipulator, located between the grabbers, is a seven-function articulated arm that can select, interchange, and operate a variety of hydraulically powered, explosively actuated tools. With the tools it can cut cable or synthetic line, torque nuts, jack, pry, wire-brush, saw, grind, drill, tap, chip, and

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1. Design for Remote Work in the Deep Ocean, by RL Wernli (NOSC), paper published in ASME publication 78-WA/OCE-4, contributed by the Ocean Engineering Division of the American Society of Mechanical Engineers for presentation at the ASME Winter Annual Meeting, San Francisco CA, 10-15 December 1978.

drive studs. The integral tool box has "pigeonholes" and brush-type retainers for the various tools and external clip mounts for the tool bits. The primary power source is a 60 V dc lead-acid battery bank, which drives a 1-gpm 2000-psi motor-pump unit for operating the manipulator and a second, high-flow, 2.5-gpm 3000-psi motor-pump unit for powering the tools. High-pressure oil for tool actuation is supplied through two external hydraulic hoses to quick disconnects at the manipulator hand. The operator controls the WSP functions from the host vehicle, through a multiplexed telemetry circuit.

SCOPE OF THIS REPORT

The basic WSP components used in the automatic tool interchange study reported here were developed in the course of the WSP program and have been employed continuously since its inception in 1972 (ref 2, 3). This report focuses on (1) the modifications and added components (ref 4) necessary to effect automation of the WSP and (2) the analyses and tests used to demonstrate the feasibility and accuracy of the automated device.

DESIGN OF THE WSP TOOL INTERCHANGE

Work systems previous to the WSP had been employed, but only one or two tools were used on a single dive. The main objective of the original WSP was to provide a large number of tools and a tool interchange capability. This was intended to allow the operator to perform very complex missions in only one dive.

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2. Development of a Design Baseline for Remotely Controlled Underwater Work Systems, by RL Wernli (NOSC); paper published in IEEE publication 78 CH 0134-7 OEC, Oceans '78, record of the Fourth Annual Combined Conference sponsored by the Marine Technological Society and the IEEE Council on Ocean Engineering, held in Washington DC, 6-8 September 1978, p 130.
3. NOSC TR 214, Evaluation of the Design and Undersea Work Capability of the Work Systems Package, by WR Bertsche, KP Logan, AN Pesch, and RL Wernli (Principal investigator), 1 April 1978.
4. NOSC TN 360, NOSC Informal Progress Report, Fiscal Year 1977; Work Systems Package (WSP) Program, by RL Wernli, 1 April 1978. NOSC TNs are informal documents intended chiefly for internal use.

The designers were concerned that the operator would find tool interchange difficult. Consequently a premise of the early design process was that tool interchange had to be conducted in the best viewing area — with some diminution of the mission operating area if necessary. Thus the large, unwieldy tool box of the WSP was located in the prime operating area. Subsequent testing and analysis demonstrated that tool interchange could be accomplished easily by means of this approach.

AUTOMATION OF THE WSP

In this study, automation of the tool interchange was considered. This approach would permit the tool box to be located outside the prime operating (viewing) area. There were two concerns:

1. There were no known automated robotic systems that worked in the deep ocean.
2. The known high precision robotics (NASA and assembly line automation) all used variable-rate control rather than fixed-rate (solenoid) control.

The WSP manipulator is factory equipped with solenoid valves (for fixed-rate control). Besides being less expensive, fixed-rate control consumes less power — an important consideration since the WSP operates on batteries and its power consumption limits its mission time.

Deep-diving manned submersibles are limited in both the power available to perform work operations and the amount of life-support power available to the crew. A reduction in overall operating time may allow a mission to be completed more quickly or may allow more work to be done per dive. For a 20 000-foot dive, the effect can have a significant impact on the overall operation of the mission. For a tethered submersible, which may have unlimited power available, time reductions would be the primary factor. During operations under adverse weather conditions, the weather window available for operation of tethered systems may be very small. Thus the importance of expedience in such missions, as was shown dramatically during the recovery of

an F-14 off Scotland.* In any case, reduction of operator fatigue — especially in a manned boat, where comfort is not the general rule — would be advantageous.

Although automatic tool interchange was considered too risky for immediate implementation in an operational WSP, a task was begun to evaluate the feasibility of automation. A programmer to effect automatic manipulator control through fixed-rate control valves was built and demonstrated on the linkage manipulator (ref 4). Since the results of this preliminary test were encouraging, it was decided to go ahead with evaluating the feasibility of automatic tool interchange on the WSP. This paper describes that effort.

SYSTEM DESCRIPTION

FUNCTIONAL DESCRIPTION

Further tool interchange technology that had to be developed before the objective could be achieved included (1) modifying the WSP manipulator by adding angular position sensors to the manipulator joints that were to be automatically controlled, (2) providing the necessary command and feedback interfaces between a microprocessor and the WSP manipulator, and (3) devising a tool-interchange computer program for the microprocessor. Tests then could be conducted to demonstrate whether automatic tool interchange could be performed repeatedly without malfunction.

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*An F-14, equipped with a Top Secret Phoenix missile, fell into 2000 feet of water from a carrier off the coast of Scotland in September 1976. Soviet trawlers observed the incident.

Recovery of the F-14 was ordered by President Ford, but the search and recovery operations took more than a month because of adverse weather conditions, typically sea state 4-5.

When the F-14 was recovered, there were two fishing nets wrapped around it. Although it was too big for the nets, the Phoenix missile easily could have been recovered accidentally by fishermen.

Figure 1 is a functional block diagram of the WSP demonstration system.

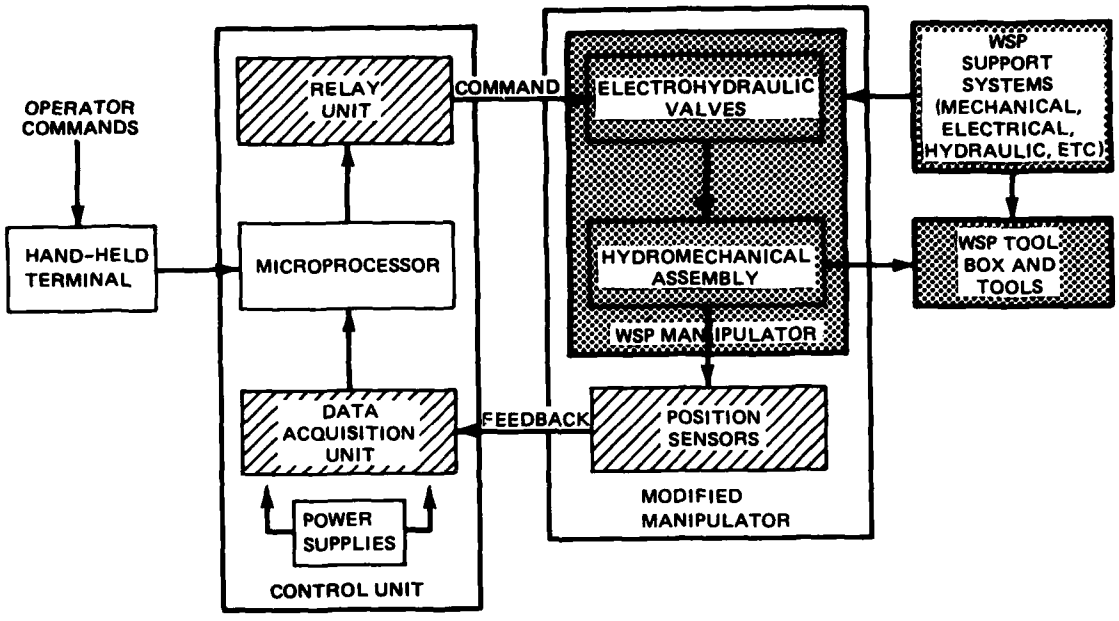

Figure 1. Automatic tool interchange demonstration system functional block diagram. The shaded areas represent existing WSP components used in the study, the cross-hatched areas represent developmental components, and the clear areas represent existing non-WSP components.

SYSTEM REQUIREMENTS

Accuracy

The basic accuracy requirement is that the manipulator be able to hit within the alignment guides on the tool. Table 1 shows the specifications derived for the WSP manipulator. It is assumed that the guides are designed for a maximum error of 0.25 inch and that the manipulator contains a tool that extends 1 foot beyond the tip of the hand.

Option	Manipulator Joint*	Position Error, inches		Angular Error, minutes	
		Nominal	Desirable	Nominal	Desirable
1—Same error for each function (standard deviation)	SL	0.045	0.020	2.0	1.0
	SU	0.045	0.020	2.0	1.0
	E	0.045	0.020	3.0	1.5
	WU	0.045	0.020	4.0	2.0
	WL	0.045	0.020	4.0	2.0
	Overall	0.100	0.040		
2—Same encoder for all functions	SL	0.055	0.020	2.5	1.0
	SU	0.055	0.020	2.5	1.0
	E	0.040	0.015	2.5	1.0
	WU	0.025	0.010	2.5	1.0
	WL	0.025	0.010	2.5	1.0
	Overall	0.100	0.040		

*SL = shoulder left/right
SU = shoulder up/down
E = elbow up/down
WU = wrist up/down
WL = wrist left/right

Table 1. Allowable position error of each manipulator arm functional element and derived allowable angular error of each associated joint.

Table 2 shows the angular ranges over which the joints with sensors can be controlled and the much narrower ranges over which a tool can be controlled accurately.

Manipulator Joint	Control Range,°	High-Accuracy Range,°*
SU	210	45
SL	180	120
E	270	**45
WU	270	**45
WL	180	5

* Subject to change, depending on tool box design and work area limits.
**These functions could be less inhibited if the elbow and wrist up/down potentiometers were not coupled to the shoulder up/down movement.

Table 2. Ranges of control and high accuracy.

Temperature Variation

Accuracy must be maintained over a temperature variation of 0° to 30°C.

Drift

Accuracy must be maintained for at least 1-2 months. If accuracy can be maintained for 1-2 years, maintenance requirements would be substantially lower. If this system is to be delivered to Navy operating forces, the 1-2 year requirement is probably necessary.

Long-Term Drift

Accuracy must be maintained over a period of 1 year. Therefore, electronics drift must be controlled.

Shock and Vibration

The system must be designed to withstand a standard shipboard environment.

Linearity

Linearity is not required but is desirable in that it would allow more sophisticated software techniques.

MANIPULATOR

The manipulator (ref 1, 3), manufactured by Programmed and Remote (PaR) Systems Corporation, is actuated by individual hydraulic motors or actuators that articulate shoulder rotate and pivot, elbow pivot, wrist rotate and pivot, and hand open and close motions. Hydraulic supply pressure to each function is gated on or off by electrical commands to associated built-in electrohydraulic solenoid valves.

POSITION ENCODING

The angle between the elements comprising each joint of the manipulator (except wrist rotate and hand open/close) must be accurately measured and converted to a voltage, to provide the feedback necessary for computer-controlled automation of the tool interchange function.

POSITION FEEDBACK TRANSDUCERS

Angular position can be sensed satisfactorily by either an absolute or an incremental encoder. The incremental encoder is easier to align when realignment is necessary, but it has to be reinitialized after power loss.

At least four types of transducers exist for this purpose:

Electromechanical (potentiometers)
Optical
Magnetic (synchros)
Mechanical (pin contacts)

Potentiometers, which are functionally absolute, may be wire-wound, ceramic-metallic (cermet), made of conductive plastic, etc. Conductive plastic potentiometers were selected for sensors in this study because they are inexpensive and easily interfaced. These potentiometers, used successfully in the demonstration, had accuracies of 1 part in 10 000. It is questionable, however, whether long-time accuracy better than 1 part in 2000 to 4000 can be achieved under shock, vibration, and variations of temperature and power-supply voltage. This degree of accuracy should be acceptable if two or more potentiometers can be stacked on the same shaft—one for coarse measurement, one for fine.

Optical encoders can be either absolute or incremental. Off-the-shelf incremental optical encoders are available with accuracies of 1 part in 20 000, but their ability to withstand pressure has not been established.

Synchros are probably the best type of position sensors. They are relatively expensive, however, and the high-accuracy versions tend to be significantly larger than potentiometers.

Pin-contact sensors do not have sufficient accuracy.

MODIFICATION DESCRIPTION

To provide angular-position feedback signals necessary for automatic operation, manipulator precision potentiometers were attached to the five applicable joints (fig 2). The devices chosen were Bourns Instrument Company 7/8-inch diameter, servomount, 10 kΩ conductive plastic potentiometers, type

6534S-1-103. They were externally mounted on the shoulder azimuth, shoulder pitch, elbow pitch, wrist pitch, and wrist azimuth functions (fig 3) by means of lightweight, inexpensive potentiometer mounts. For simplicity of operation, wrist rotation and hand open/close were operated by direct switch control, without feedback.

CONTROL UNIT

The control unit (showing in the background, fig 3) consists of a microprocessor, a relay unit, a data acquisition unit, and associated power supplies. The microprocessor is programmed as follows:

1. To respond to discrete control signals from the hand-held terminal function buttons by causing the relay unit to send various combinations of electrical commands to the electrohydraulic valve solenoids, driving the manipulator in selected motions.

2. To stop the manipulator motions at predetermined positions of the manipulator hand as determined by processing feedback voltages received via the data acquisition unit from the manipulator joint angular sensors.

TERMINAL

The hand-held terminal, manufactured by Termiflex (fig 4), was adapted for operator programming and command input to the control unit and for limited CRT display of monitored functions. It is ideal for use in the confined environment of a manned submersible. The operator inserts codified instructions into the microprocessor by punching appropriate pushbuttons on the terminal's miniature keyboard.

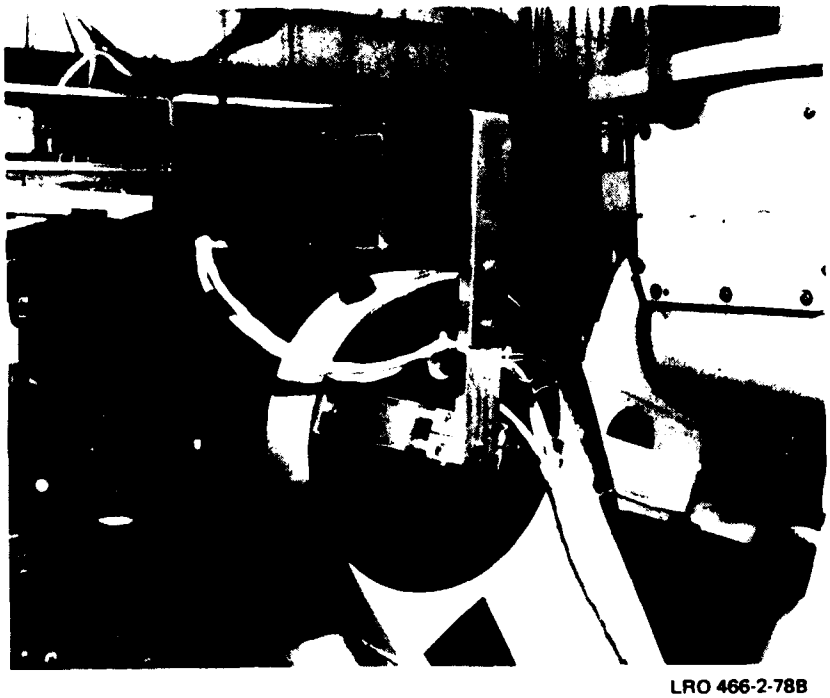

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Figure 2. Closeup of one of five potentiometer mounts on WSP manipulator.

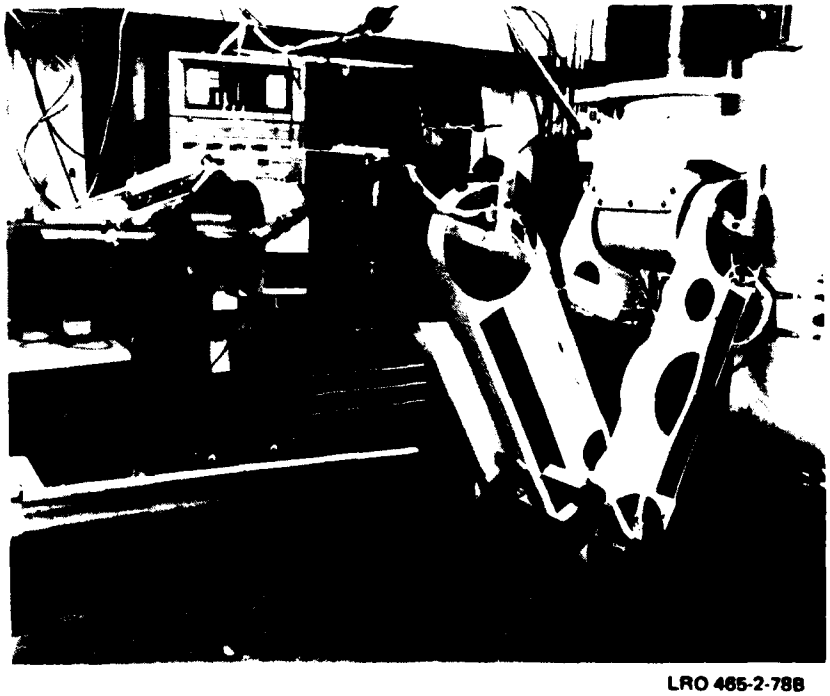

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Figure 3. Overall view of WSP manipulator with position encoding potentiometers mounted appropriately at joints.

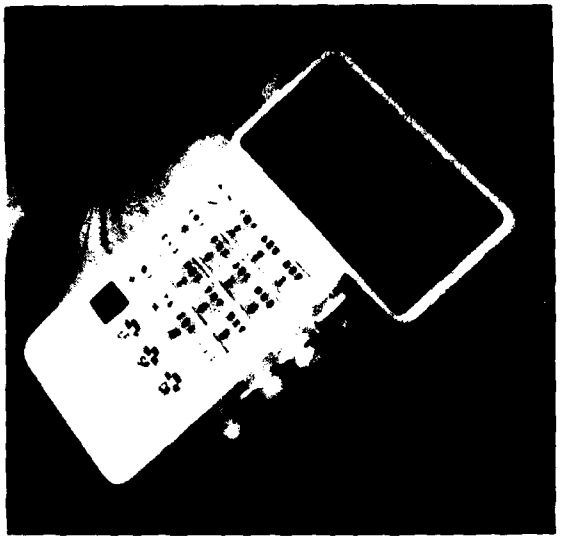

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Figure 4. Termiflex HT/2 hand-held computer terminal.

TOOL BOX AND TOOLS

The tool box (fig 5) and tools used in the study were those developed for the WSP (ref 1).

PROGRAMMER

DESIGN REQUIREMENTS

Precision control of a solenoid-controlled manipulator is a significantly different process from precision control of a servo-controlled manipulator. A servo unit can be slowed down as it approaches the desired point. A solenoid unit, however, is turned off abruptly somewhat before reaching the desired point; its final position depends on how far it moves during valve closure.

LRO 4851-8-77

Figure 5. Tool box.

The algorithm for the control unit is as follows:

1. Determine which direction to move manipulator.
2. Open solenoid; manipulator starts moving.
3. Monitor position of manipulator.
4. When manipulator reaches critical position, turn off (close) solenoids.
5. Effect no further control until manipulator stops moving. (There may be several oscillations.)
6. Compare final position of manipulator to desired position. If error is significant, try again.

Several quantitative data values are associated with each movement, as follows.

Desired Location

The desired location (preprogrammed) is selected by the operator. The coordinates of the desired location are initially determined by moving the arm to that location and automatically reading the coordinates (potentiometer readings). Known coordinates can be entered by the operator.

Tolerable Error

The maximum error is based on the following model. The manipulator is moved towards the tool box by using five functions in a sequence. The final operation — extend — consists of two simultaneous functions. On this final extend operation, the manipulator must contact the alignment grooves on the tool box. When the manipulator hand reaches the tool box, the maximum correctable error is 1/4 inch in any direction, within a plane perpendicular to the extend function travel. (This is discussed further in appendix C.)

Solenoid Turn-off Point

The "coasting time" is a function of the following:

Individual manipulator function.

Direction of travel. The length of coast is greater for down movement than for up movements.

Weight of manipulator. Usually this factor is limited to the weight of the object being transported.

Hydraulic pressure. The hydraulic pressure drops when more than one function is operated. Consequently it is difficult to estimate the coasting time if another function is operated and the one which will turn off first is not known.

Water depth. Ambient pressure increases with depth. This may affect the coasting time, but there are no data available.

Required Feedback Sampling Rate

The sampling rate is determined primarily by the rate at which the arm moves. The worst-case sample rate occurs with shoulder movements since they move the fastest. Shoulder movements cause the hand to move through an arc of about 7-foot radius. At 1.26 rpm, the tip speed is thus 11 inches per second. The shoulder has a nominal accuracy of 0.05 inch (see appendix C). The manipulator travels 0.05 inch in about 4.5 ms. Consequently, the decision time should be less than 450 μs. A 45-μs decision time was established as a design goal to eliminate this parameter as a problem. The final design required 30 μs between decisions (33 kHz sample rate).

FUNCTIONAL DESCRIPTION

The control unit contains the following components:

Data acquisition unit

Microprocessor

Hand-held terminal

Relays

Data Acquisition Unit

Potentiometers are attached to the manipulator. A precision voltage source (20 ± 0.001 V) provides power to the potentiometers via a shielded twisted pair. Other shielded twisted pairs bring the wiper voltage and the negative reference to the analog multiplexer.

The analog multiplexer has two stages. The first stage selects two potentiometer signals and inputs them into high-accuracy, slow-settling, differential instrumentation amplifiers. The second stage is used for the rapid selection of one of the two signals selected by the first stage. This signal is measured by a high-speed 14-bit analog-to-digital converter. The A/D converter and multiplexer operate under computer control.

Microprocessor

An Intel 8080 microcomputer monitors the potentiometers and controls the relays as commanded by the operator. The computer contains random access memory so that the operator can program manipulator sequences, then perform them. Also provided is erasable programmable read-only memory (EPROM), for long-term storage of preprogrammed manipulator sequences.

Hand-Held Terminal

The Work System Package was designed to be attached to the Alvin submersible. To meet this requirement, the manipulator was controlled from a small hand-held box. For the purpose of this study, a small hand-held computer terminal (Termiflex HT-2) was selected to perform the operator-machine interface. The primary limitation on such a device is the display rather than the controls. The terminal displays two lines of ten alphanumeric characters each. It also has a scroll capability with access to 100 lines. The interface was designed so that the operator receives immediate feedback from only the last two lines of data. Consequently the operator normally does

not have to use the scroll feature, although it is available for reviewing previous operations.

Relays

Telephone-type relays are used to select two solenoids. Two solid-state relays are then used to turn the solenoids on and off in a predictable time period. (Note: tests on the linkage manipulator used reed relays because of different electrical requirements.)

TEST DESCRIPTION

FUNCTIONAL TESTS

First, three elementary tests were made on the automated system. The first of these was to acquire a tool and a bit and then to move to the work area, where control was returned to the operator. The second was to return the tool and bit to the tool box. The third was to drill a hole automatically.

Next, these three separate sequences were linked together. Without any intervention by the operator, the programmer was able to direct the manipulator to obtain the drill and bit, drill a hole, and return the tools to the tool box.

A fallback objective was also considered: to evaluate the mating (and/or disconnect) of the tool and manipulator, which is the most critical operation. In still another test, the microcomputer was programmed to position the manipulator directly in front of the tool such that the operator could easily acquire the tool.

In actual practice in the deep ocean, the automatic operation should stop at these critical points and allow the operator to look at the manipulator through the TV. When the manipulator has acquired a tool, the operator must make a visual check to see that the tool is securely locked onto the manipulator before the tool is brought out. Similarly the operator must make sure that the tool is released after it is replaced so that the manipulator does not drag it back out, causing it to fall to the ocean floor. Note that the operator needs only one TV camera for these critical checks, since he is not actually controlling the manipulator.

There was no attempt to run the automatic controller fast. In fact, it was slowed down at every opportunity in the effort to obtain consistently reliable results. Sequential operation was programmed, wherever feasible. Intermediate stopping points were programmed in. After each move, the controller waited for the arm to come to a complete rest. (This precaution was not always necessary.)

Despite these limitations, however, the system performed faster under programmed operation than under manual. Time reductions in operation are important since they lower the energy storage requirements of battery-operated submersibles or other platforms on which such a system would be used. Microcomputer control allowed the manipulator to repeat motions with such accuracy that tool and bit exchanges were successfully completed under exclusive control of the programmer.

Note that the configuration of the WSP was optimized for manual operation; if a less exposed position were chosen for tool-box placement, as could be done with automatic tool exchange, further improvement in operation could be expected. Although the functional test established that complete tool interchange could be programmed and accomplished without human intervention, simple movement to a point in space was complicated by tool-box compliance (as well as a manipulator malfunction). Programming the tool interchange process was far more difficult than anticipated. The problems experienced are each discussed briefly as follows, along with their solutions.

The WSP was designed to acquire tools with a final movement in which the manipulator hand extends linearly in the proper direction. But in the linear extend function, the manipulator arm was found to experience a significant droop. The linear extend function requires simultaneous actuation of the shoulder up and elbow down functions. The up function requires the greater amount of power, to overcome gravity, but the power input is the same for each function since all solenoid valves and hydraulic actuators of the manipulator are identical. The solution to this problem was to program a series of intermediate points at each of which the position of the hand would be corrected.

Attempts to extend directly toward the center of the tool were successful only part of the time; the manipulator hand frequently would hit an adjacent tool bin. The operator could avoid this problem by manually controlling the nonautomated hand open/close and wrist rotate. (The computer does not have a feedback sensor on those functions.) This obstacle was removed by programming the manipulator to move to a point about 1 inch from the tool and 0.25 inch off center, then to realign both the shoulder and wrist left-right functions to the center of the tool.

Grasping the tool required that significant pressure be exerted on it. This could not be programmed simultaneously with position control, since the tool box would move substantially before the pressure became sufficient to overcome binding between the tool and the tool box, and any movement accompanied by binding would cause significant change in the position of the tool box. It was found that grasping the tool could be accomplished sequentially, by careful alignment at the final intermediate position followed by a 5-second linear extend.

The tool acquisition phase ends with the tool box pushed several inches from its normal position and the tool locked in the box by binding forces. Tool removal from the box is difficult because of the binding tendencies of the very compliant tool box. "Nonlinear" retraction also causes binding. It was found that removal of the tool could be accomplished by realigning the manipulator every 2 inches or so.

The movement for tool insertion into the tool box after use is entirely different from the tool acquisition movement. It was solved primarily by programming in a large number of intermediate "stopping for realignment" points.

Removal of the hand after tool insertion into the tool box is difficult, since the hand tends to pull the tool back out. Inadvertent pullout of the tool was minimized by programming in several sequential small movements alternating with realignments.

Tool seating, the final step in tool stowage, is achieved by a separate sequence of closing the manipulator hand, then pushing the tool with the tip of the hand for several seconds.

A problem that occurred throughout the tests is that moving one function would cause the potentiometer of another function to change. Specifically, moving the shoulder up or down caused three potentiometers to change (shoulder up/down, elbow up/down, and wrist up/down). Also, the elbow up/down function caused movement of the wrist up/down potentiometer. If the potentiometers had 0.001% linearity, these changes could have been compensated for. Since they were only about 0.01% linear, however, it was necessary to move the shoulder up/down to a known position before the elbow up/down could be aligned precisely. Alignment of the wrist up/down was more complex, since before it could be aligned, both the shoulder up/down and the elbow up/down had to be moved to known locations. This problem could be cured by attaching the potentiometers such that they would be moved independently.

ACCURACY TESTS

Several types of accuracy tests were performed next for the purpose of determining the expected consistency of performance, helping identify problem areas, and discovering the cause and magnitude of errors so that means could be devised to correct them. The objectives of the tests were as follows:

1. Estimate the overall accuracy of the programmer.
2. Estimate the mean and variance of the coasting distance* for the shoulder, elbow, and wrist function movements.
3. Estimate the error contribution due to each of those functions.

At the conclusion of these tests, potentiometer noise was measured to determine its effect upon accuracy.

The tests were performed in the following sequence. The programmer was directed to move the manipulator through a series of tool exchanges and, between each exchange, to return it to a predesignated location about 6 feet from the manipulator shoulder pivot point, aligned with a specific spot on a target. After completion of the movement, the alignment error at the target was measured with a ruler and protractor. In addition, the predicted errors were read out of the control unit and recorded.

Two sets of ten identical movements were performed. The standard deviation was determined, and further analysis was done to determine the cause of error.

The manipulator movements were determined by the solenoid turn-off points. These were determined with sufficient accuracy to verify that the system passed the tests, but the programmer was not adjusted to yield optimal results. The errors were averaged to determine the true point to which the manipulator was programmed to move, and all further analyses used this point as a reference.

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*The distance traveled after the command is issued to turn off the solenoid valve.

TEST RESULTS

STANDARD DEVIATION

At the end of each movement (tool exchange), the error relative to the desired point was measured. These data contain a systematic error in that the programming was not optimal. The error was then calculated relative to the mean of the final positions. (Position was described by means of clock notation.)

The error relative to the reference point was less than 1/4 inch in all cases (table 3). The standard deviation of the error was 0.108 inch. This indicates a 98% probability of meeting the requirements on each movement; ie, alignments would have to be repeated less than 2% of the time.

Run	Total Error		Error Relative to Mean	
	Magnitude, fraction of inch	Position, o'clock	Magnitude, fraction of inch	Position, o'clock
1	1/8	9	0.06	8
2	1/8	9	0.06	8
3	1/8	9	0.06	8
4	1/8	9	0.06	8
5	1/8	9	0.06	8
6	1/32	9	0.07	4
7	1/8	9	0.06	8
8	1/8	9	0.06	8
9	1/8	10	0.03	8
10	3/16	7	0.21	6
11	1/8	12	0.12	2
12	1/8	12	0.12	2
13	1/8	12	0.12	2
14	1/8	12	0.12	2
15	0	—	0.10	4
16	1/16	9	0.05	5
17	3/16	10	0.09	10
18	1/8	8	0.11	6
19	1/4	11	0.18	12
20	1/4	11	0.18	12

Mean of the final positions: = -0.085 inch, = +0.043 inch
Standard deviation = 0.108 inch
Standard deviation (left/right only) = 0.057 inch
Standard deviation (up/down only) = 0.092 inch

Table 3. Programmer accuracy test results.

CONTROL UNIT ERROR READINGS

Control unit error readings were taken for each potentiometer at the end of each test movement. Error was measured in parts per 16 000 relative to the preprogrammed reference point. The control unit readings (table 4) were used to estimate coasting distances and accuracies for each of the individual functions. The results were as follows.

	Manipulator Accuracy, potentiometer readings.				
Test No	Shoulder Up/Down	Elbow Up/Down	Wrist Up/Down	Shoulder Right/Left	Wrist Right/Left
1	-4	-4	4	4	4
2	-1	-1	4	5	-5
3	-3	-1	4	2	-3
4	+1	-2	6	4	0
5	-3	-2	6	2	-2
6	0	-1	6	2	-1
7	-4	-1	5	1	-2
8	-1	0	5	0	-3
9	-1	-1	5	0	1
10	-2	0	5	2	3
11	+1	-6	4	2	10
12	-3	0	7	1	4
13	-1	0	8	-5	5
14	-3	0	8	0	10
15	-4	-3	-10*	0	8
16	-2	-2	-11*	0	7
17	-5	-1	8	1	4
18	-4	-2	-6	-1	5
19	-4	-1	8	0	8
20	-3	0	7	-3	5
Mean	-2.55	-1.4	+3.6	+0.85	+3.10
Standard deviation	1.6	1.5	5.6	2.3	4.6

*Solenoid actuated (see text)

Table 4. Control unit error reading. To convert control unit error into absolute error: 1 part in 16 000 over 270° represents 1 minute of arc, or 0.017°.

Shoulder Up/Down

The shoulder up/down function had a dead-band width of 24 units (0.63 inch). The arm coasted 9.5 units (0.24 inch) with a standard deviation of 1.6 units (0.040 inch).

Elbow Up/Down

The elbow up/down function had a dead-band width of 40 units (0.71 inch). The arm coasted 18.6 units (0.33 inch) with a standard deviation of 1.5 units (0.027 inch).

Wrist Up/Down

The wrist up/down function had a dead-band width of 24 units (1.14 inches). The coasting distance could not be accurately estimated since there were two wrist alignments during the final movement and only the first movement was actuated during 17 of 20 tries. (Note: the first ten movements had three wrist up/down movements; the last ten had four wrist up/down movements.)

The wrist up/down function was inconsistent during the final ten runs because of a programming error. Dead-band was set at ±5 units. The previous position was very close, about -3.5 units, with the result that the solenoids were not activated about 50% of the time. When the previous position was -5 or lower, the solenoids would be activated and the wrist up/down moved to +2 units; ie, the wrist up/down went to one of two positions that were 0.25 inch apart.

Shoulder Left/Right

The shoulder left/right function had a dead-band of 40 units (1.00 inch). The arm coasted 17.5 units (0.438 inch) with a standard deviation of 2.3 units (0.058 inch).

Wrist Left/Right

The wrist left/right function had a dead-band of 40 units (0.40 inch). The arm coasted 23.5 units (0.23 inch) with a standard deviation of 4.6 units (0.046 inch). Further analysis indicated that there was a significant difference between the first ten movements and the second ten. The first ten coasted an average of 19.2 units (0.19 inch) with a standard deviation of 2.8 units (0.028 inch), while the second ten coasted an average of 27 units (0.27 inch) with a standard deviation of 2.3 units (0.23 inch).

These coasting distance results are summarized in table 5.

Function	Dead-Band Width	Distance to Drill, feet
Shoulder left/right	±20 units at 0.026 = 0.52 inch	6
Shoulder up/down	±12 units at 0.026 = +0.31 inch	
Elbow up/down	±20 units at 0.0177 = 0.35 inch	4.25
Wrist left/right	±20 units at 0.010 = 0.20 inch	2.5
Wrist up/down	± 12 units at 0.0475 = 0.57 inch	

Table 5. Coasting distance results.

The overall accuracy, calculated for the control unit readings, was essentially the same as the measured accuracy (table 6), although the data were uncorrelated. This indicated that there was a problem in the control unit rather than in the manipulator.

Measured Overall Standard Deviation (measured with ruler and protractor, 20 trials)	Inches	Minutes of Arc
LEFT/RIGHT	0.057	
Up/down	0.092	
Vertical alignment	0.0	
Horizontal alignment	0.0	
Combined total	0.108	
Calculated Overall Standard Deviation (calculated from potentiometer readings)		
a. Up/down		
Shoulder up/down	0.040	2.0
Elbow up/down	0.027	1.9
Wrist up/down	0.057*	7.0*
Combined up/down standard deviation	0.075	
b. Left/right		
Shoulder left/right	0.058	2.9
Wrist left/right	0.046	5.8
Combined left/right standard deviation	0.074	
Calculated total (a + b) standard deviation	0.104	

*Should have been 0.015 inch and 1.9 minutes of arc.

Table 6. Manipulator accuracy.

POTENTIOMETER NOISE

A static measurement of potentiometer noise showed that a 4 mV, 60 Hz signal was present. This effectively degraded the data acquisition to 1 part in 4000 rather than 1 part in 16 000. The signal was found to be electromagnetic radiation from the WSP low-pressure hydraulic pump. This will not be a problem in the water, but better electromagnetic shielding is required for lab testing. (The wiring to the potentiometers consisted of shielded twisted pairs, but the potentiometers and electronics were not shielded.)

RISK FACTORS

Automatic tool interchange is not without disadvantages. System automation often results in added complexity and lower reliability. The principal source of concern in the automatic tool interchange study is the reliability of manipulator joint position sensors, which must work under the extreme ambient pressures of the deep ocean. The rest of the electronics, which are easier to house and protect, are felt to have a negligible impact on system reliability. For follow-on development, this problem would be minimized by employing good design, quality assurance measures, and comprehensive testing.

CONCLUSIONS

1. The feasibility of automatic tool interchange with a WSP comprising a compliant tool box and a compliant undersea manipulator was demonstrated in the laboratory.

2. Equipped with fixed-rate position control, the WSP performed automatic tool interchange repeatedly without malfunction.

RECOMMENDATIONS

1. Incorporate automation into the next work system that is built.

2. Ultimately, conduct in-water tests of the automated work system to verify its feasibility.

APPENDIX A: OPERATOR-MACHINE INTERFACE

This appendix lists some of the commands which an operator might wish to use during operation (table A1) and during programming (table A2).

It was not feasible to include all of these commands in this feasibility demonstration. Table A3 lists the commands which are available to an operator and table A4 lists the commands which are used to program a sequential operation.

Functional Inputs

1. Go to tool location _xx_ and retrieve the _yy_ tool (bit).
2. Store tool (bit) _xx_ (which manipulator already has) into tool location _yy_.
3. Remember the present position of the manipulator and call it _xx_.
4. Go to the position which was previously tagged as _xx_.
5. Stow manipulator into a compact position for transport.
6. Unstow manipulator from transport position into work position.

Functional Outputs

1. Selected button is acknowledge (multifunction buttons acknowledged by multifunction display).
2. Error conditions displayed:

    a. Manipulator does not respond (_x_ seconds of "on" time does not produce _y_ degrees of travel).
    b. Manipulator overshoots desired location by _x_ degrees.
    c. Power-supply failures and other routine electronic malfunctions if not displayed elsewhere.
    d. Hydraulic system failures not displayed elsewhere.

Table A1. Operation.

Functional Inputs

Program

1. The name of this sequence is _x_ (_x_ is a reference to console inputs).
2. Move the manipulator function _x_ to the _y_ position.
3. Continue to next step in the sequence.
4. Activate manipulator function _x_ for _y_ seconds.
5. End of sequence; turn off all manipulator functions. (TRANSFER)
6. Wait until all presently activated functions are complete, then go to next step in sequence.

Functional Outputs

Display inputs as required for next section.

1. Display program sequence _y_.
2. Display present position.
3. Display diagnostic information during execution of a sequence.

Table A2. Programming

Display Options

1. Display individual potentiometer reading.
2. Update potentiometer reading at ten samples per second.
3. Display all potentiometer readings.
4. Update all potentiometer readings.
5. Display a programmed sequence of commands.

Manipulator Operating Commands

1. Execute a preprogrammed sequence of operations. Name of operation will be displayed before and during operation.
2. Execute an operator-programmed sequence of operations. This does not have a name.
3. Display diagnostic information during operation.
4. The operation may be stopped any time.

Programming Commands

1. Any command listed in table A1 may be entered anywhere in the sequence.
2. Commands can be transferred from one location to another.
3. Entire command sequence (preprogrammed or programmed) can be inserted into the new sequence.
4. The present manipulator position may be automatically entered.

Table A3. Commands used by the operator.

Single Function Position Commands

1. Move shoulder up/down to XXXX OXXO.
2. Move shoulder left/right to XXXX OXXO.
3. Move elbow up/down to XXXX OXXO.
4. Move wrist up/down to XXXX OXXO.
5. Move wrist left/right to XXXX OXXO.
6. Operate hand open for 3.5 seconds.
7. Operate hand close for 3.5 seconds.

Multiple Function Position Commands

8. Extend/retract to XXXX OXXO.
   (Operates either shoulder up and elbow down or shoulder down and elbow up by means of the shoulder up/down potentiometer.)
9. Extend for 3.5 seconds.
   (Operates shoulder up and elbow down.)
10. Stop.

Table A4. Programming commands. Any number of these commands can be executed sequentially.

APPENDIX B: COMPUTER PROGRAM

```
ASM80 :F1:DACQ.ASY XREF PAGEWIDTH(72) PRINT(:LP:)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         DACQ     PAGE    1


  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    DACQ
                       2
                       3 ;PROGRAMMER:  C. MORRIN
                       4 ;VERSION 2.1
                       5 ;DATE OF LAST CHANGE:  OCTOBER 25, 1977
                       6
                       7 ;*************************************************
                       8
                       9          CSEG
                      10
                      11          PUBLIC  DISPOT,SETMUX,GETDAT,SAVE
                      12          PUBLIC  GETPOT,ADONLY
                      13          EXTRN   OUTPUT,FNASC,WAIT,HEXASC
                      14          EXTRN   OPINFO,MUXAD,PRADD
                      15
                      16 ;*************************************************
                      17
                      18 ;DISPLAY POTENTIOMETER ROUTINE (DISPOT).
                      19 ;FUNCTION TO BE DISPLAYED IS IN REG A.
                      20 ;DISPOT GETS THE CURRENT VALUE OF THE POT,
                      21 ;AND OUTPUTS ' FF-XXXX' TO THE HAND CONTROLLER.
                      22
  0000 C5             23 DISPOT: PUSH    B
  0001 E5             24         PUSH    H
  0002 4F             25         MOV     C,A     ;GET READY FOR SMUX
  0003 CD5700    C    26         CALL    SMUX
  0006 CD9E00    C    27         CALL    GETDAT
  0009 CD3200    C    28         CALL    SAVE
                      29 ;STORES DATA IN OPINFO+7 TO +10
  000C 79             30         MOV     A,C
                      31 ;FNASC REQUIRES FUNCTION IN ACC
  000D CD0000    E    32         CALL    FNASC
                      33 ;ASCII FUNCTION IS NOW IN OPINFO+4,+5
                      34 ;OPINFO+3 IS ' ',OPINFO+6 IS '-'
  0010 210300    E    35         LXI     H,OPINFO+3
  0013 0E08           36         MVI     C,8
  0015 CD0000    E    37         CALL    OUTPUT  ;' FF-XXXX'
  0018 E1             38         POP     H
  0019 C1             39         POP     B
  001A C9             40         RET
                      41
                      42 ;*************************************************
                      43
  001B D5             44 GETPOT: PUSH    D
  001C E5             45         PUSH    H
  001D CD9200    C    46         CALL    SETMUX
  0020 CD9E00    C    47         CALL    GETDAT
  0023 EB             48         XCHG
  0024 2A0000    E    49         LHLD    PRADD
  0027 23             50         INX     H
  0028 72             51         MOV     M,D
  0029 23             52         INX     H
  002A 73             53         MOV     M,E
  002B EB             54         XCHG
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

002C CD3200   C     55          CALL    SAVE
                    56 ;DATA WILL BE PUT INTO OPINFO+7 TO +10
002F E1             57          POP     H
0030 01             58          POP     D
0031 C9             59          RET
                    60
                    61 ;***********************************************
                    62
                    63 ;SAVE DATA ROUTINE (SAVE):
                    64 ;DATA WILL BE PLACED IN OPINFO+7 TO +10
                    65 ;A/D DATA MUST BE IN REG HL
                    66
0032 F5             67 SAVE:    PUSH PSW
0033 C5             68          PUSH B
0034 D5             69          PUSH D
0035 97             70          SUB     A
0036 110700   E     71          LXI     D,OPINFO+7
0039 0E04           72          MVI     C,4H
003B 0604           73 TSFT4:   MVI     B,4H
                    74 ;TRIPLE SHIFT ACC AND HL FOUR PLACES
003D 29             75          DAD     H
003E 17             76          RAL
003F 05             77          DCR     B
0040 C23D00   C     78          JNZ     TSFT4+2
0043 CD0000   E     79          CALL    HEXASC
0046 12             80          STAX    D  ;STORE DATA IN OPINFO+7-10
0047 13             81          INX     D
0048 0D             82          DCR     C
0049 C23B00   C     83          JNZ     TSFT4
004C D1             84          POP     D
004D C1             85          POP     B
004E F1             86          POP     PSW
004F C9             87          RET
                    88
                    89 ;ADONLY READS A/D AND SAVES DATA IN OPINFO+7-10
0050 CD9E00   C     90 ADONLY:  CALL    GETDAT
0053 CD3200   C     91          CALL    SAVE
0056 C9             92          RET
                    93
                    94 ;***********************************************
                    95
                    96 ;SMUX ROUTINE
                    97 ;REQUIRES FUNCTION IN REG C
                    98 ;FORMAT:          XXXXX000 = SU
                    99 ;                 XXXXX001 = SL
                   100 ;                 XXXXX010 = EU
                   101 ;                 XXXXX011 = EE
                   102 ;                 XXXXX100 = WU
                   103 ;                 XXXXX101 = WL
                   104 ;                 XXXXX110 = WR
                   105 ;
                   106 ;MUX FORMAT (8255 REG C, ADDRESS = MUXA0+2)
                   107 ;       000XXXXX = SU = FUNCTION #1
                   108 ;       001XXXXX = EU = FUNCTION #2
                   109 ;       010XXXXX = SL = FUNCTION #3
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

                    110 ;       011XXXXX = WU = FUNCTION #4
                    111 ;       1XX00XXX = WL = FUNCTION #5
                    112 ;       1XX01XXX = ?? = FUNCTION #6
                    113 ;       1XX10XXX = ?? = FUNCTION #7
                    114 ;       XXXXXXXN = A/D START (N =NEG EDGE)
                    115
0057 F5             116 SMUX:   PUSH    PSW
0058 C5             117         PUSH    B
0059 D5             118         PUSH    D
005A E5             119         PUSH    H
005B 3E07           120         MVI     A,7
005D A1             121         ANA     C
005E 0600           122         MVI     B,0
0060 CA8300    C    123         JZ      DONE    ;SU
0063 3D             124         DCR     A
0064 0640           125         MVI     B,40H
0066 CA8300    C    126         JZ      DONE    ;SL
0069 0620           127         MVI     B,20H
006B 3D             128         DCR     A
006C CA8300    C    129         JZ      DONE    ;EU
006F 0600           130         MVI     B,0
0071 3D             131         DCR     A
0072 CA8300    C    132         JZ      DONE    ;EE
0075 0660           133         MVI     B,60H
0077 3D             134         DCR     A
0078 CA8300    C    135         JZ      DONE    ;WU
007B 0680           136         MVI     B,80H
007D 3D             137         DCR     A
007E CA8300    C    138         JZ      DONE    ;WL
0081 0690           139         MVI     B,90H
0083 78             140 DONE:   MOV     A,B
0084 320200    E    141         STA     MUXAD+2
0087 01C300         142         LXI     B,200
008A CD0000    E    143         CALL    WAIT
                    144 ;WAIT 10MS FOR OP AMP TO SETTLE
008D E1             145         POP     H
008E D1             146         POP     D
008F C1             147         POP     B
0090 F1             148         POP     PSW
0091 C9             149         RET
                    150
                    151 ;***********************************************
                    152
                    153 ;SETMUX SETS THE MULTIPLEXOR TO THE
                    154 ;FUNCTION POINTED TO BY PRADD
0092 E5             155 SETMUX: PUSH    H
0093 C5             156         PUSH    B
0094 2A0000    E    157         LHLD    PRADD
0097 4E             158         MOV     C,M
0098 CD5700    C    159         CALL    SMUX
009B C1             160         POP     B
009C E1             161         POP     H
009D C9             162         RET
                    163
                    164 ;***********************************************
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

                    165
                    166 ;GETDAT STARTS THE A/D CONVERTER,
                    167 ;THEN READS IT WHEN DONE
 009E F5            168 GETDAT: PUSH    PSW
 009F C5            169         PUSH    B
 00A0 3E01          170         MVI     A,1
 00A2 320300    E   171         STA     MUXAD+3
 00A5 3E00          172         MVI     A,0
 00A7 320300    E   173         STA     MUXAD+3   ;START A/D
 00AA 010100        174         LXI     B,1
 00AD CD0000    E   175         CALL    WAIT
 00B0 2A0000    E   176         LHLD    MUXAD
 00B3 C1            177         POP     B
 00B4 F1            178         POP     PSW
 00B5 C9            179         RET               ;A/D DATA IS IN HL
                    180
                    181         END
```

```
PUBLIC SYMBOLS
ADONLY C 0050    DISPOT C 0000    GETDAT C 009E    GETPOT C 001B
SAVE   C 0032    SETMUX C 0092

EXTERNAL SYMBOLS
FNASC  E 0000    HEXASC E 0000    MUXAD  E 0000    OPINFO E 0000
OUTPUT E 0000    PRADD  E 0000    WAIT   E 0000

USER SYMBOLS
ADONLY C 0050    DISPOT C 0000    DONE   C 0083    FNASC  E 0000
GETDAT C 009E    GETPOT C 001B    HEXASC E 0000    MUXAD  E 0000
OPINFO E 0000    OUTPUT E 0000    PRADD  E 0000    SAVE   C 0032
SETMUX C 0092    SMUX   C 0057    TSFT4  C 003B    WAIT   E 0000

ASSEMBLY COMPLETE,  NO ERRORS
```

```
ADONLY   12     90#
@ACQ      1
DISPOT   11     23#
@DNE    123    126    129    132    135    138    140#
FNASC    13     32
GETDAT   11     27     47     90    168#
GETPOT   12     44#
HEXASC   13     79
MUXAD    14    141    171    173    176
OPINFO   14     35     71
OUTPUT   13     37
PRADD    14     49    157
SAVE     11     28     55     67#    91
SETMUX   11     46    155#
SMUX     26    116#   159
TSFT4    73#    78     83
WAIT     13    143    175

CROSS REFERENCE COMPLETE
```

```
ASM80 :F1:DELAY.ASY XREF PAGEWIDTH(72) PRINT(:LP:)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0          DELAY     PAGE     1


  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    DELAY
                       2
                       3 ;PROGRAMMER: C.MORRIN
                       4 ;VERSION 1.0
                       5 ;DATE OF LAST CHANGE:  OCTOBER 31, 1977
                       6
                       7 ;VARIABLE DELAY ROUTINE
                       8 ;REGISTER BC CONTAINS DELAY
                       9 ;DELAY = 50 MICROSECONDS X (BC)
                      10
                      11 ;IMPLEMENTATION:  RTC#1 LOADED WITH DELAY.
                      12 ;WHEN FINISHED RTC#2 SENDS SIGNAL
                      13 ;TO 8259 INTERRUPT CHIP WHICH CALLS
                      14 ;INTIAL ROUTINE WHICH JUMPS TO "WAIT1".
                      15 ;"WAIT2" IS THE WAITING PLACE
                      16 ;DURING THE COUNTDOWN.
                      17
                      18          CSEG
                      19
                      20          PUBLIC  WAIT,WAIT1
                      21          EXTRN   RTCAD,INTAD,WFLAG
                      22
  0000 E5             23 WAIT:    PUSH    H
  0001 D5             24          PUSH    D
  0002 F5             25          PUSH    PSW
  0003 210300    E    26          LXI     H,RTCAD+3 ;BC CONTAINS DELAY
  0006 3670           27          MVI     M,70H     ;SET RTC1 TO MODE 0
  0008 2B             28          DCX     H
  0009 2B             29          DCX     H
  000A 71             30          MOV     M,C       ;LOAD RTC#1 = REG BC
  000B 70             31          MOV     M,B
  000C F3             32          DI
  000D 210100    E    33          LXI     H,INTAD+1
  0010 5E             34          MOV     E,M       ;GET CURRENT MASK
  0011 36BF           35          MVI     M,0BFH    ;MASK ALL BUT RTC1
  0013 2B             36          DCX     H
  0014 3685           37          MVI     M,85H   ;OCW2: RTC#1 TOP PRIORITY
  0016 3E01           38          MVI     A,1
  0018 320000    E    39          STA     WFLAG
  001B FB             40 WAIT2:   EI
  001C 3A0000    E    41          LDA     WFLAG
  001F E6FF           42          ANI     0FFH      ;SET ACC FLAGS
  0021 C21B00    C    43          JNZ     WAIT2     ;WAIT FOR RTC#1 INTERRUP
                         T
  0024 F3             44          DI
  0025 7B             45          MOV     A,E       ;GET SAVED MASK
  0026 F640           46          ORI     40H       ;MASK OUT RTC1
  0028 210100    E    47          LXI     H,INTAD+1
  002B 77             48          MOV     M,A       ;OCW1: SET MASK
  002C 2B             49          DCX     H
  002D 3666           50          MVI     M,66H     ;OCW2: END OF RTC1 INT
  002F 3684           51          MVI     M,84H     ;OCW2: UART TOP PRIORITY
  0031 F1             52          POP     PSW
  0032 D1             53          POP     D
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         DELAY    PAGE    2


  LOC  OBJ          LINE        SOURCE STATEMENT

  0033 E1             54          POP     H
  0034 FB             55          EI
  0035 C9             56          RET
                      57
                      58 ;+++++++++++++++++++++++++++++++++++++++++++++++++
  0036 F5             59 WAIT1:   PUSH    PSW
  0037 3E00           60          MVI     A,0
  0039 320000    E    61          STA     WFLAG
  003C F1             62          POP     PSW
  003D C9             63          RET             ;RETURN TO WAIT2
                      64
                      65          END


PUBLIC SYMBOLS
WAIT   C 0000    WAIT1  C 0036

EXTERNAL SYMBOLS
INTAD  E 0000    RTCAD  E 0000    WFLAG  E 0000

USER SYMBOLS
INTAD  E 0000    RTCAD  E 0000    WAIT   C 0000    WAIT1  C 0036
WAIT2  C 001B    WFLAG  E 0000

ASSEMBLY COMPLETE,   NO ERRORS
```

```
ISIS-II ASSEMBLER SYMBOL CROSS REFERENCE, V2.1                    PAGE   1

DELAY      1
INTAD     21      33      47
RTCAD     21      26
WAIT      20      23#
WAIT1     20      59#
WAIT2     40#     43
WFLAG     21      39      41      61

CROSS REFERENCE COMPLETE
```

```
ASM80 :F1:EPROMW.ASY XREF PAGEWIDTH(72) PRINT(:LP:)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0          EPROMW   PAGE    1


  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    EPROMW
                       2
                       3 ;PROGRAMMER: C. MORRIN
                       4 ;VERSION:  2.0W
                       5 ;DATE OF LAST CHANGE:  NOVEMBER 7, 1977
                       6
                       7 ;*************************************************
                       8
                       9          DSEG
                      10
                      11          PUBLIC  H0,H1,H2,H3,H4
                      12          PUBLIC  H5,H6,H7,H8,H9
                      13
                      14 ;*************************************************
                      15 ;FUNCTION DEFINITIONS:
                      16
  0000                17 SU       EQU     0
  0001                18 SL       EQU     1
  0002                19 EU       EQU     2
  0003                20 EE       EQU     3
  0004                21 WU       EQU     4
  0005                22 WL       EQU     5
  0008                23 H0       EQU     8
  0009                24 HC       EQU     9
  000E                25 EX       EQU     0EH
                      26
  00FF                27 STOP     EQU     0FFH
                      28
                      29 ;*************************************************
                      30 ;PROG*AD=*0
                      31 ;MOVE ARM TO NEUTRAL POSITION
  0000 00             32 H0:      DB      SU,6AH,44H,5
  0001 6A
  0002 44
  0003 05
  0004 01             33          DB      SL,62H,88H,5
  0005 62
  0006 88
  0007 05
  0008 02             34          DB      EU,2BH,0E4H,5
  0009 2B
  000A E4
  000B 05
  000C 04             35          DB      WU,7EH,0D0H,5
  000D 7E
  000E D0
  000F 05
  0010 05             36          DB      WL,7BH,0CCH,5
  0011 7B
  0012 CC
  0013 05
  0014 FF             37          DB      STOP
                      38
                      39 ;+++++++++++++++++++++++++++++++++++++++++++++++++
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

                    40 ;PROG*AD=*1
                    41 ;GO TO TOOL #1:
0015 05             42 H1:      DB      WL,7CH,34H,3
0016 7C
0017 34
0018 03
0019 08             43          DB      HO,0,0,0
001A 00
001B 00
001C 00
001D 01             44          DB      SL,8BH,0C0H,5
001E 8B
001F C0
0020 05
                    45
0021 00             46          DB      SU,68H,84H,3
0022 68
0023 84
0024 03
0025 02             47          DB      EU,22H,74H,5
0026 22
0027 74
0028 05
0029 04             48          DB      WU,81H,50H,3
002A 81
002B 50
002C 03
                    49
002D 03             50          DB      EE,70H,0,3
002E 70
002F 00
0030 03
0031 00             51          DB      SU,78H,0B4H,3
0032 78
0033 B4
0034 03
0035 02             52          DB      EU 38H,0B0H,5
0036 38
0037 B0
0038 05
                    53
0039 03             54          DB      EE,7CH,0ACH,3
003A 7C
003B AC
003C 03
003D 00             55          DB      SU,7EH,0ACH,3
003E 7E
003F AC
0040 03
0041 02             56          DB      EU,43H,0B4H,5
0042 43
0043 B4
0044 05
                    57
0045 03             58          DB      EE,81H,0,3
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0046 81
0047 00
0048 03
0049 00             59          DB      SU,83H,90H,3
004A 83
004B 90
004C 03
004D 02             60          DB      EU,4CH,0BCH,5
004E 4C
004F BC
0050 05
                    61
0051 03             62          DB      EE,85H,0ACH,3
0052 85
0053 AC
0054 03
0055 00             63          DB      SU,86H,0ACH,3
0056 86
0057 AC
0058 03
0059 02             64          DB      EU,51H,88H,5
005A 51
005B 88
005C 05
                    65
005D 01             66          DB      SL,8BH,0,7
005E 8B
005F 00
0060 07
0061 05             67          DB      WL,7AH,0,3
0062 7A
0063 00
0064 03
                    68
0065 03             69          DB      EE,87H,0,3
0066 87
0067 00
0068 03
0069 09             70          DB      HC,0,0,0
006A 00
006B 00
006C 00
006D 0E             71          DB      EX,0,0,0
006E 00
006F 00
0070 00
0071 FF             72          DB      STOP
                    73
                    74  ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    75  ;PROG*AD=*2
                    76  ;BACK AWAY FROM TOOL #1 (WITH OR WITHOUT TOOL)
0072 03             77  H2:     DB      EE,83H,90H,3
0073 83
0074 90
0075 03
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0076 02             78          DB      EU,4CH,0BCH,5
0077 4C
0078 BC
0079 05
                    79
007A 03             80          DB      EE,7EH,0CCH,3
007B 7E
007C CC
007D 03
007E 02             81          DB      EU,43H,0B4H,5
007F 43
0080 B4
0081 05
                    82
0082 03             83          DB      EE,70H,0,5
0083 70
0084 00
0085 05
0086 FF             84          DB      STOP
                    85
                    86 ;++++++++++++++++++++++++++++++++++++++++++++++++
                    87 ;PROG*AD=*3
                    88 ;GO TO BIT #1 (WITH TOOL #1)
0087 01             89 H3:      DB      SL,6AH,0,7
0088 6A
0089 00
008A 07
008B 05             90          DB      WL,75H,08H,3
008C 75
008D 08
008E 03
                    91
008F 00             92          DB      SU,93H,4CH,3
0090 93
0091 4C
0092 03
0093 02             93          DB      EU,3AH,0ACH,5
0094 3A
0095 AC
0096 05
0097 04             94          DB      WU,79H,0ECH,3
0098 79
0099 EC
009A 03
                    95
009B 01             96          DB      SL,6FH,90H,5
009C 6F
009D 90
009E 05
009F 05             97          DB      WL,75H,08H,3
00A0 75
00A1 08
00A2 03
00A3 04             98          DB      WU,7CH,0E4H,3
00A4 7C
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

00A5 E4
00A6 03
00A7 FF             99          DB      STOP
                   100
                   101 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   102 ;PROG*AD=*4
                   103 ;MOVE TOOL+BIT TO METAL PLATE AND ALIGN
00A8 01            104 H4:     DB      SL,60H,54H,5
00A9 60
00AA 54
00AB 05
00AC 05            105         DB      WL,7CH,8CH,5
00AD 7C
00AE 8C
00AF 05
                   106
00B0 04            107         DB      WU,9CH,4CH,4
00B1 9C
00B2 4C
00B3 04
00B4 00            108         DB      SU,80H,0ACH,3
00B5 80
00B6 AC
00B7 03
00B8 02            109         DB      EU,3CH,68H,5
00B9 3C
00BA 68
00BB 05
                   110
00BC 00            111         DB      SU,64H,0ECH,3
00BD 64
00BE EC
00BF 03
00C0 02            112         DB      EU,37H,0B4H,5
00C1 37
00C2 B4
00C3 05
00C4 04            113         DB      WU,70H,0FCH,3
00C5 70
00C6 FC
00C7 03
                   114
00C8 03            115         DB      EE,68H,70H,3
00C9 68
00CA 70
00CB 03
00CC 00            116         DB      SU,6BH,70H,3
00CD 6B
00CE 70
00CF 03
00D0 02            117         DB      EU,42H,8CH,5
00D1 42
00D2 8C
00D3 05
                   118
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

00D4 FF            119          DB      STOP
                   120
                   121 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   122 ;PROG*AD=*5
                   123 ;RETURN BIT $1 TO TOOL RACK:
00D5 05            124 H5:      DB      WL,76H,0D8H,3
00D6 76
00D7 D8
00D8 03
00D9 01            125          DB      SL,6AH,0C0H,5
00DA 6A
00DB C0
00DC 05
                   126
00DD 00            127          DB      SU,99H,0E0H,3
00DE 99
00DF E0
00E0 03
00E1 02            128          DB      EU,42H,0ABH,5
00E2 42
00E3 AB
00E4 05
00E5 04            129          DB      WU,78H,0,3
00E6 78
00E7 00
00E8 03
                   130
00E9 01            131          DB      SL,6FH,0C0H,5
00EA 6F
00EB C0
00EC 05
00ED 04            132          DB      WU,7DH,0BCH,3
00EE 7D
00EF BC
00F0 03
                   133
00F1 05            134          DB      WL,75H,0ACH,3
00F2 75
00F3 AC
00F4 03
00F5 04            135          DB      WU,7EH,50H,3
00F6 7E
00F7 50
00F8 03
                   136
00F9 05            137          DB      WL,74H,14H,3
00FA 74
00FB 14
00FC 03
00FD 04            138          DB      WU,7FH,6CH,3
00FE 7F
00FF 6C
0100 03
                   139
0101 05            140          DB      WL,74H,14H,3
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0102 74
0103 14
0104 03
0105 04            141          DB      WU,7FH,6CH,3
0106 7F
0107 6C
0108 03
                   142
0109 03            143          DB      EE,8DH,0B0H,3
010A 8D
010B B0
010C 03
010D FF            144          DB      STOP
                   145
                   146 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   147 ;PROG*AD=*6
                   148 ;STORE TOOL #1 AFTER STORING BIT #1
010E 01            149 H6:      DB      SL,5FH,6CH,3
010F 5F
0110 6C
0111 03
0112 05            150          DB      WL,7AH,0ECH,3
0113 7A
0114 EC
0115 03
                   151
0116 04            152          DB      WU,9CH,4CH,3
0117 9C
0118 4C
0119 03
011A 00            153          DB      SU,80H,0ACH,3
011B 80
011C AC
011D 03
011E 02            154          DB      EU,3CH,68H,5
011F 3C
0120 68
0121 05
                   155
0122 00            156          DB      SU,68H,84H,3
0123 68
0124 84
0125 03
0126 02            157          DB      EU,22H,74H,5
0127 22
0128 74
0129 05
012A 04            158          DB      WU,81H,50H,3
012B 81
012C 50
012D 03
                   159
012E 01            160          DB      SL,8BH,7CH,7
012F 8B
0130 7C
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0131 07
                  161
0132 03           162         DB      EE,6EH,0,3
0133 6E
0134 00
0135 03
0136 00           163         DB      SU,78H,0B4H,3
0137 78
0138 B4
0139 03
013A 02           164         DB      EU,38H,0B0H,5
013B 38
013C B0
013D 05
                  165
013E 03           166         DB      EE,7CH,0ACH,3
013F 7C
0140 AC
0141 03
0142 00           167         DB      SU,7EH,0CCH,3
0143 7E
0144 CC
0145 03
0146 02           168         DB      EU,43H,0B4H,5
0147 43
0148 B4
0149 05
                  169
014A 03           170         DB      EE,81H,0,3
014B 81
014C 00
014D 03
014E 00           171         DB      SU,83H,90H,3
014F 83
0150 90
0151 03
0152 02           172         DB      EU,4CH,0BCH,5
0153 4C
0154 BC
0155 05
                  173
0156 0E           174         DB      EX,0,0,0
0157 00
0158 00
0159 00
015A 08           175         DB      H0,0,0,0
015B 00
015C 00
015D 00
015E FF           176         DB      STOP
                  177
                  178
                  179 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                  180 ;STORE TOOL#1 FROM NEUTRAL
015F 05           181 H7:     DB      HL,7CH,34H,5
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0160 7C
0161 34
0162 05
                  182
0163 00           183         DB      SU,68H,84H,3
0164 68
0165 84
0166 03
0167 02           184         DB      EU,22H,74H,5
0168 22
0169 74
016A 05
016B 04           185         DB      WU,81H,50H,3
016C 81
016D 50
016E 03
                  186
016F 01           187         DB      SL,8BH,7CH,7
0170 8B
0171 7C
0172 07
                  188
0173 03           189         DB      EE,6EH,0,3
0174 6E
0175 00
0176 03
0177 00           190         DB      SU,78H,0B4H,3
0178 78
0179 B4
017A 03
017B 02           191         DB      EU,3BH,0B0H,5
017C 3B
017D B0
017E 05
                  192
017F 03           193         DB      EE,7CH,0ACH,3
0180 7C
0181 AC
0182 03
0183 00           194         DB      SU,7EH,0CCH,3
0184 7E
0185 CC
0186 03
0187 02           195         DB      EU,43H,0B4H,5
0188 43
0189 B4
018A 05
                  196
018B 03           197         DB      EE,81H,0,3
018C 81
018D 00
018E 03
018F 00           198         DB      SU,83H,90H,3
0190 83
0191 90
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0192 03
0193 02            199          DB      EU,4CH,0BCH,5
0194 4C
0195 BC
0196 05
                   200
0197 0E            201          DB      EX,0,0,0
0198 00
0199 00
019A 00
019B 08            202          DB      HO,0,0,0
019C 00
019D 00
019E 00
019F FF            203          DB      STOP
                   204
                   205 ;PUSH TOOL #1 IN AFTER STORING
01A0 03            206 H8:      DB      EE,83H,90H,3
01A1 83
01A2 90
01A3 03
01A4 02            207          DB      EU,4CH,0BCH,5
01A5 4C
01A6 BC
01A7 05
01A8 03            208          DB      EE,7EH,0CCH,3
01A9 7E
01AA CC
01AB 03
01AC 02            209          DB      EU,43H,0B4H,5
01AD 43
01AE B4
01AF 05
                   210
01B0 03            211          DB      EE,7AH,74H,3
01B1 7A
01B2 74
01B3 03
01B4 09            212          DB      HC,0,0,0
01B5 00
01B6 00
01B7 00
01B8 02            213          DB      EU,3CH,18H,5
01B9 3C
01BA 18
01BB 05
01BC 04            214          DB      WU,79H,0C0H,3
01BD 79
01BE C0
01BF 03
                   215
01C0 03            216          DB      EE,7CH,0FBH,3
01C1 7C
01C2 FB
01C3 03
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 01C4 00            217         DB      SU,7DH,0FBH,3
 01C5 7D
 01C6 FB
 01C7 03
 01C8 02            218         DB      EU,41H,14H,5
 01C9 41
 01CA 14
 01CB 05
                    219
 01CC 03            220         DB      EE,70H,0,3
 01CD 70
 01CE 00
 01CF 03
 01D0 FF            221         DB      STOP
                    222
 01D1 FF            223 H9:     DB      0FFH,0FFH,0FFH,0FFH
 01D2 FF
 01D3 FF
 01D4 FF
 01D5 FF            224         DB      STOP
                    225
                    226         END

PUBLIC SYMBOLS
H0      D 0000    H1      D 0015    H2      D 0072    H3      D 0087
H4      D 00A8    H5      D 00D5    H6      D 010E    H7      D 015F
H8      D 01A0    H9      D 01D1

EXTERNAL SYMBOLS


USER SYMBOLS
EE      A 0003    EU      A 0002    EX      A 000E    H0      D 0000
H1      D 0015    H2      D 0072    H3      D 0087    H4      D 00A8
H5      D 00D5    H6      D 010E    H7      D 015F    H8      D 01A0
H9      D 01D1    HC      A 0009    HO      A 0008    SL      A 0001
STOP    A 00FF    SU      A 0000    WL      A 0005    WU      A 0004

ASSEMBLY COMPLETE,  NO ERRORS
```

EE	20#	50	54	58	62	69	77	80	83
	113	143	162	166	170	189	193	197	206
	208	211	216	220					
EPROMW	1								
EU	19#	34	47	52	56	60	64	78	81
	93	109	112	117	128	154	157	164	168
	172	184	191	195	199	207	209	213	218
EX	25#	71	174	201					
H0	11	32#							
H1	11	42#							
H2	11	77#							
H3	11	89#							
H4	11	104#							
H5	12	124#							
H6	12	149#							
H7	12	181#							
H8	12	206#							
H9	12	223#							
HC	24#	70	212						
HO	23#	43	175	202					
SL	18#	33	44	66	89	96	104	125	131
	149	160	187						
STOP	27#	37	72	84	99	119	144	176	203
	221	224							
SU	17#	32	46	51	55	59	63	92	108
	111	116	127	153	156	163	167	171	183
	190	194	198	217					
WL	22#	36	42	67	90	97	105	124	134
	137	140	150	181					
WU	21#	35	48	94	98	107	113	129	132
	135	138	141	152	158	185	214		

CROSS REFERENCE COMPLETE

```
ASM80 :F1:EXECN.ASY XREF PAGEWIDTH(72)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0          EXECW    PAGE    1

  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    EXECW
                       2
                       3 ;PROGRAMMER: C. MORRIN
                       4 ;VERSION 2.0W
                       5 ;DATE OF LAST CHANGE:  OCTOBER 31, 1977
                       6
                       7 ;*************************************************
                       8
                       9          PUBLIC  RTCAD,MUXAD,RELAY1,RELAY2
                      10          PUBLIC  EXEC,INTAD,START1,USRT
                      11          PUBLIC  DIRFLG,ARELAY,OVRFLG,STATE
                      12          PUBLIC  PRADD,OPINFO,WFLAG,POTFLG
                      13          PUBLIC  FINAL,CUTOFF,DISPFG,TAD
                      14          PUBLIC  COUNT,STOPFG
                      15          EXTRN   WAIT,WAIT1
                      16          EXTRN   INPUT,OUTPUT,INPT1
                      17
                      18
                      19          DSEG
                      20
                      21 ;*************************************************
                      22 ;SYSTEM OUTPUT PORT DEFINITION:
                      23 ;OUTPUT PORTS ARE MEMORY MAPPED:
  F900                24 RTCAD    EQU     0F900H ;8253 REAL TIME CLOCK
  F400                25 MUXAD    EQU     0F400H ;MULTIPLEXER, A/D CONTROL
  FD00                26 RELAY1   EQU     0FD00H ;RELAY CONTROL
  F500                27 RELAY2   EQU     0F500H ;RELAY CONTROL
  FC00                28 INTAD    EQU     0FC00H ;8259 INTERRUPT CONTROLLE
                         R
  F800                29 USRT     EQU     0F800H ;8251 USART ADDRESS
                      30
                      31 ;*************************************************
                      32 ;SYSTEM MEMORY DEFINITION:
  F000                33 DIRFLG   EQU     0F000H    ;SEE OPERAT
  F001                34 ARELAY   EQU     DIRFLG+1  ;SEE RELAY
  F003                35 OVRFLG   EQU     ARELAY+2  ;SEE OPERAT
  F004                36 STATE    EQU     OVRFLG+1  ;SEE INPUT
  F006                37 PRADD    EQU     STATE+2   ;SEE PROGRM
  F008                38 OPINFO   EQU     PRADD+2   ;SEE PROGRM
  F016                39 WFLAG    EQU     OPINFO+14;SEE DELAY
  F017                40 POTFLG   EQU     WFLAG+1   ;SEE DACQ
  F019                41 FINAL    EQU     POTFLG+2  ;SEE OPERAT
  F01B                42 CUTOFF   EQU     FINAL+2   ;SEE OPERAT
  F01D                43 DISPFG   EQU     CUTOFF+2  ;SEE OPERAT
  F01E                44 TAD      EQU     DISPFG+1  ;SEE PROGRM
  F020                45 COUNT    EQU     TAD+2     ;SEE OPERN
  F021                46 STOPFG   EQU     COUNT+1 ;SEE OUTPUT
                      47 ;STOPFG IS 1 BYTE
                      48
                      49 ;*************************************************
                      50 ;OUTPUT MESSAGES:
                      51
  0000 2050524F       52 OTABLE: DB       ' PROGRAM=P OPERATE=O'
  0004 4752414D
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 0008 3D50204F
 000C 50455241
 0010 54453D4F
 0014 2052442A      53 OTABL1: DB      ' RD*POTS=R DISPLAY=D'
 0018 504F5453
 001C 3D522044
 0020 4953504C
 0024 41593D44
 0014               54 LTABLE  EQU     20
 0014               55 LTABL1  EQU     20
                    56
                    57 ;************************************************
                    58
                    59         CSEG
                    60
                    61 ;EXEC ROUTINE:
                    62 ;EXEC PROVIDES A WAITING PLACE WHEN NEEDED
 0000 F3            63 EXEC:   DI
 0001 2101FC        64         LXI     H,INTAD+1
 0004 7E            65         MOV     A,M
 0005 E6DF          66         ANI     0DFH
 0007 77            67         MOV     M,A
 0008 FB            68         EI
 0009 00            69         NOP
 000A 00            70         NOP
 000B 00            71         NOP
 000C C30000    C   72         JMP     EXEC
                    73
                    74 ;************************************************
                    75
                    76 ;INITIALIZATION ROUTINE
                    77
                    78 ;THIS ROUTINE INITIALIZES ALL HARDWARE
                    79 ; AND SOFTWARE INCLUDING:
                    80 ;       8080 STACK POINTER
                    81 ;       8251 USRT
                    82 ;       8253 REAL TIME CLOCK
                    83 ;       8255 DATA ACQUISTION INTERFACE
                    84 ;       8255 RELAY INTERFACE
                    85 ;       8259 INTERRUPT CONTROLLER
                    86 ;       STATE
                    87 ;       PRADD
                    88 ;       OPINFO (HYPHENS AND SPACES ONLY)
                    89 ;       OVRFLG (OPERAT ROUTINE)
                    90 ;       HAND CONTROLLER DISPLAY
                    91 ;
                    92 ;INITIAL ROUTINE INITIALIZES AFTER A
                    93 ; POWER ON RESET OR A SOFTWARE RESET.
                    94 ;8253 USES COUNTER 0 TO DIVIDE THE 2MHZ CLOCK TO
                    95 ; 19 KHZ TO DRIVE COUNTERS 1 AND 2 PLUS THE USRT
                       .
                    96 ; COUNTER 1 IS THE RTC.  COUNTER 2 IS NOT USED.
                    97 ;
                    98 ;8255 DATA ACQUISTION INTERFACE INPUTS A/D DATA
                    99 ; ON PORTS A AND B.  IT CONTROLS THE A/D START
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

                    100 ; AND THE MULTIPLEXORS ON PORT C.
                    101 ;
                    102 ;ALL EXCEPT RXRDY ARE MASKED
                    103 ;
                    104 ;VECTOR ROUTINE VECTORS INTERRUPTS FROM 8259 TO
                    105 ;PROPER SUBROUTINES
                    106 ;
                    107 ;EXEC PROVIDES A WAITING PLACE WHEN REQUIRED
                    108
                    109         ASEG
                    110
0000                111         ORG     0H
0000 F3             112 START:  DI
                    113
                    114 ;STACK POINTER INITIALIZATION:
0001 31FFF0         115         LXI     SP,0F0FFH
                    116
                    117 ;8253 (REAL TIME CLOCK) INITIALIZATION
0004 2103F9         118         LXI     H,RTCAD+3
0007 3616           119         MVI     M,16H   ;RTC#0 = MODE 3,LSB ONLY
0009 3670           120         MVI     M,70H   ;RTC#1 = MODE 0
000B 36AA           121         MVI     M,0AAH ;RTC#2 = MODE 5,MSB ONLY
000D 2100F9         122         LXI     H,RTCAD
0010 366A           123         MVI     M,106   ;RTC#0 = 19.32 KHZ
                    124 ;NOTE:  RTC#1 SET BY DELAY ROUTINE (WAIT)
                    125 ;       RTC#2 NOT USED
                    126
                    127 ;8255 (I/O PORT) INITIALIZATION
0012 2103F4         128         LXI     H,MUXAD+3
                    129 ;PORTS A&B = INPUT (A/D)
0015 3692           130         MVI     M,92H
                    131 ;PORT  C  = OUTPUT (MUX,A/D)
                    132
0017 C30F00    C    133         JMP START2
                    134
                    135 ;*************************************************
                    136
                    137 ;THE FOLLOWING TABLE IS CALLED BY
                    138 ;THE 8259 INTERRUPT CONTROLLER
                    139
                    140         ASEG
                    141
0020                142         ORG     20H
0020 C9             143         RET
                    144
0024                145         ORG     24H
0024 C9             146         RET
                    147
0028                148         ORG     28H
0028 C9             149         RET
                    150
002C                151         ORG     2CH
002C C9             152         RET
                    153
0030                154         ORG     30H
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0030 C9            155         RET             ;TXRDY INTERRUPT
                   156
0034               157         ORG     34H
0034 F3            158         DI
0035 C30000    E   159         JMP     INPUT   ;RXRDY INTERRUPT
                   160
0038               161         ORG     38H
0038 F3            162         DI
0039 C30000    E   163         JMP     WAIT1   ;RTC1 INTERRUPT
                   164
003C               165         ORG     3CH
003C C9            166         RET             ;RTC2 INTERRUPT
                   167
                   168 ;*************************************************
                   169
                   170 ;INITIALIZATION ROUTINE (CONTINUED)
                   171
                   172         CSEG
                   173
                   174 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   175 ;8255 RELAY PORT INITIALIZATION:
000F 3E80          176 START2: MVI     A,80H
0011 3203FD        177         STA     RELAY1+3 ;ALL PORTS = OUTPUT
0014 3E00          178         MVI     A,0
0016 3202FD        179         STA     RELAY1+2 ;TURN OFF RELAYS
                   180
                   181 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   182 ;8259 (INTERRUPT CONTROLLER) INITIALIZATION
0019 2100FC        183         LXI     H,INTAD
001C 3636          184         MVI     M,36H   ;ICW1: INTERVAL=4,
                   185 ; START AT XX20H
001E 23            186         INX     H
001F 3600          187         MVI     M,0
                   188 ;ICW2: START AT 00XXH
0021 36DF          189         MVI     M,0DFH
                   190 ;OCW1: MASK ALL BUT RXRDY (USRT)
0023 2B            191         DCX     H
0024 3684          192         MVI     M,84H
                   193 ;OCW2: INPUT HAS HIGHEST PRIORITY
                   194
                   195 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   196 ;8251 (USRT) INITIALIZATION
0026 2101F8        197         LXI     H,USRT+1
0029 3641          198         MVI     M,41H   ;IF 1ST, SET MODE=ASYNC
                   199                         ;IF 2ND, RESET
002B 3601          200         MVI     M,01H   ;IF 2ND, HARMLESS
                   201                         ;IF 1ST, SET MODE=ASYNC
002D 3640          202         MVI     M,40H   ;2ND: RESET 8251
002F 367A          203         MVI     M,7AH   ;MODE = 1 STOP BIT,
                   204 ;EVEN PARITY, PARITY ENABLE, 7 BIT CHARACTER,
                   205 ; 16X CLK
0031 3617          206         MVI     M,17H   ;COMMAND = NO HUNT,
                   207 ; NO RESET, NO RTS, ERROR RESET,
                   208 ; NO BREAK CHAR, RECIEVE ENABLE,
                   209 ;ENABLE DATA TERMINAL READY (DTR = LOW),
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

                   210 ; TRANSMIT ENABLE
                   211
                   212 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   213 ;INITIALIZE OPINFO TABLE
0033 3E20          214         MVI     A,' '
0035 3208F0        215         STA     OPINFO
0038 320BF0        216         STA     OPINFO+3
003B 3E2D          217         MVI     A,'-'
003D 320EF0        218         STA     OPINFO+6
0040 3213F0        219         STA     OPINFO+11
                   220
                   221 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   222 ;INITIALIZE OVRFLG
0043 3E00          223         MVI     A,0
0045 3203F0        224         STA     OVRFLG
                   225
                   226 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   227 ;INITIALIZE HAND CONTROLLER DISPLAY
0048 211400    D   228         LXI     H,OTABL1
004B 0E14          229         MVI     C,LTABL1
004D CD0000    E   230         CALL    OUTPUT  ;' RD*POTS=R DISPLAY=D'
0050 01204E        231         LXI     B,20000
0053 CD0000    E   232         CALL    WAIT    ;WAIT 1 SECOND
0056 210000    D   233         LXI     H,OTABLE
0059 0E14          234         MVI     C,LTABLE
005B CD0000    E   235         CALL    OUTPUT  ;' PROGRAM=P OPERATE=O'
                   236
                   237 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   238 ;INITIALIZE STATE
005E 210000    E   239         LXI     H,INPT1
0061 2204F0        240         SHLD    STATE
                   241
                   242 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   243 ;INITIALIZE PRADD
0064 2107F0        244         LXI     H,PRADD+1;INITIALIZE PRADD
0067 36F1          245         MVI     M,0F1H  ;PROGRAM MEMORY = F1XXH
                   246
                   247 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   248 ;INITIALIZE DISPFG
0069 3A1DF0        249         LDA     DISPFG
006C FE00          250         CPI     0
006E CA0000    C   251         JZ      EXEC    ;DISPFG RESET
0071 FE0F          252         CPI     0FH
0073 CA0000    C   253         JZ      EXEC    ;DISPFG SET
                   254 ;DISFLG NEEDS INITIALIZATION:
0076 3E00          255         MVI     A,0
0078 321DF0        256         STA     DISPFG
                   257 ;NO DIAGNOSTICS DURING OPERATION
007B C30000    C   258         JMP     EXEC
                   259
                   260 ;#################################################
                   261 ;SOFTWARE RESET:
007E 01F401        262 START1: LXI     B,500
0081 CD0000    E   263         CALL    WAIT
                   264 ;WAIT 25MS FOR THE 8251 TO FINISH TRANSMITTING
```

```
  LOC  OBJ          LINE         SOURCE STATEMENT

  0084 C30000        265          JMP     START
                     266
                     267          END


PUBLIC SYMBOLS
ARELAY A F001    COUNT  A F020    CUTOFF A F01B    DIRFLG A F000
DISPFG A F01D    EXEC   C 0000    FINAL  A F019    INTAD  A FC00
MUXAD  A F400    OPINFO A F008    OVRFLG A F003    POTFLG A F017
PRADD  A F006    RELAY1 A FD00    RELAY2 A F500    RTCAD  A F900
START1 C 007E    STATE  A F004    STOPFG A F021    TAD    A F01E
USRT   A F800    WFLAG  A F016

EXTERNAL SYMBOLS
INPT1  E 0000    INPUT  E 0000    OUTPUT E 0000    WAIT   E 0000
WAIT1  E 0000

USER SYMBOLS
ARELAY A F001    COUNT  A F020    CUTOFF A F01B    DIRFLG A F000
DISPFG A F01D    EXEC   C 0000    FINAL  A F019    INPT1  E 0000
INPUT  E 0000    INTAD  A FC00    LTABL1 A 0014    LTABLE A 0014
MUXAD  A F400    OPINFO A F008    OTABL1 D 0014    OTABLE D 0000
OUTPUT E 0000    OVRFLG A F003    POTFLG A F017    PRADD  A F006
RELAY1 A FD00    RELAY2 A F500    RTCAD  A F900    START  A 0000
START1 C 007E    START2 C 000F    STATE  A F004    STOPFG A F021
TAD    A F01E    USRT   A F800    WAIT   E 0000    WAIT1  E 0000
WFLAG  A F016

ASSEMBLY COMPLETE,  NO ERRORS
```

```
ARELAY    11      34#     35
COUNT     14      45#     46
CUTOFF    13      42#     43
DIRFLG    11      33#     34
DISPFG    13      43#     44     249     256
EXEC      10      63#     72     251     253     258
EXECW      1
FINAL     13      41#     42
INPT1     16     239
INPUT     16     159
INTAD     10      28#     64     183
LTABL1    55#    229
LTABLE    54#    234
MUXAD      9      25#    128
OPINFO    12      38#     39     215     216     218     219
OTABL1    53#    228
OTABLE    52#    233
OUTPUT    16     230     235
OVRFLG    11      35#     36     224
POTFLG    12      40#     41
PRADD     12      37#     38     244
RELAY1     9      26#    177     179
RELAY2     9      27#
RTCAD      9      24#    118     122
START    112#    265
START1    10     262#
START2   133     176#
STATE     11      36#     37     240
STOPFG    14      46#
TAD       13      44#     45
USRT      10      29#    197
WAIT      15     232     263
WAIT1     15     163
WFLAG     12      39#     40

CROSS REFERENCE COMPLETE
```

```
ASM80 :F1:INPUT.ASY XREF PAGEWIDTH(72)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0        INPUT     PAGE     1


  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    INPUT
                       2
                       3 ;PROGRAMMER:  C.MORRIN
                       4 ;VERSION 2.0
                       5 ;DATE OF LAST CHANGE:  NOVEMBER 2, 1977
                       6
                       7 ;*************************************************
                       8
                       9          CSEG
                      10
                      11          PUBLIC  INPUT,INPT1,ERROR,EXIT
                      12          PUBLIC  ASCHEX,ASCHX1
                      13          EXTRN   PROGR,OPER,DISP,RDPOT,ATTRIB
                      14          EXTRN   INTAD,USRT,STATE,WAIT
                      15          EXTRN   HEXASC,XMIT,START1
                      16
                      17 ;*************************************************
                      18
                      19 ;USART RECEIVER INTERFACE ROUTINE:
                      20
                      21 ;INPUT IS CALLED BY THE 8259 INTERRUPT CONTROLLE
                         R
                      22 ;WHEN THE 8251 RXRDY STATUS LINE INDICATES THAT
                      23 ;A CHARACTER HAS BEEN RECEIVED.
                      24
                      25 ;USRT RECEIVER READY, JUMP TO ENTRY POINT
                      26 ;INDICATED BY ADDRESS POINTER "STATE":
0000 3A0100    E     27 INPUT:  LDA     USRT+1   ;GET STATUS
0003 E638            28          ANI     38H      ;MASK FOR ERROR FIELD
0005 C21400    C     29          JNZ     ERR
0008 2A0000    E     30          LHLD    STATE
000B 3A0000    E     31          LDA     USRT     ;GET DATA
000E FE1A            32          CPI     1AH      ;"CONTROL Z"
0010 CA0000    E     33          JZ      START1
0013 E9              34          PCHL
                     35
                     36 ;+++++++++++++++++++++++++++++++++++++++++++++++++
0014 3A0100    E     37 ERR:    LDA     USRT+1   ;GET STATUS AGAIN
0017 E601            38          ANI     1        ;MASK ALL BUT TXRDY
0019 C21400    C     39          JNZ     ERR
                     40 ;WAIT UNTIL DATA BUS BUFFER IS EMPTY
                     41 ;(IT WILL BE FULL IF TRANSMITTER IS GOING)
001C 3E17            42          MVI     A,17H
001E 320100    E     43          STA     USRT+1   ;RESET 8251 ERROR FLAGS
0021 3A0000    E     44          LDA     USRT     ;CLEAR RECEIVER
0024 019001          45          LXI     B,400
0027 CD0000    E     46          CALL    WAIT
002A 3A0000    E     47          LDA     USRT     ;CLEAR RECEIVER AGAIN
002D C34900    C     48          JMP     ERROR
                     49
                     50 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                     51 ;PROGRAM, OPERATE, DISPLAY, OR READ POTS?
0030 FE50            52 INPT1:  CPI     50H      ;COMPARE WITH 'P'
0032 CA0000    E     53          JZ      PROGR
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0035 FE4F           54          CPI     4FH     ;COMPARE WITH 'O'
0037 CA0000    E    55          JZ      OPER
003A FE44           56          CPI     'D'
003C CA0000    E    57          JZ      DISP    ;JUMP TO DISPLAY ROUTINE
003F FE52           58          CPI     'R'
0041 CA0000    E    59          JZ      RDPOT
0044 FE41           60          CPI     'A'
0046 CA0000    E    61          JZ      ATTRIB
                    62
                    63 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    64 ;INCORRECT INPUT, IGNORE INPUT & AND RING BELL:
0049 3E07           65 ERROR:   MVI     A,7H    ;RING BELL
004B CD0000    E    66          CALL    XMIT
004E C35400    C    67          JMP     EXIT+3
                    68
                    69 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    70 ;ALL ROUTINES WHICH ARE INDIRECTLY CALLED
                    71 ;BY INPUT RETURN TO EXIT TO END THE INTERRUPT:
0051 220000    E    72 EXIT:    SHLD    STATE   ;SET NEW STATE
0054 F3             73          DI
                    74 ;8259 MUST RECEIVE END OF INTERRUPT BEFORE
                    75 ;ALLOWING INPUT ROUTINE TO BE CALLED AGAIN:
0055 3E65           76          MVI     A,65H   ;OCW2: END OF INPUT INT
0057 320000    E    77          STA     INTAD
005A FB             78          EI
005B C9             79          RET
                    80
                    81 ;*************************************************
                    82
                    83 ;ASCII TO HEXADECIMAL CONVERSION ROUTINES.
                    84
                    85 ;ALL ROUTINES START AND END WITH DATA IN ACC
                    86 ;ASCHEX = ASCII TO HEX (HEX: LOWER HALF ACC)
                    87 ;ASCHX1 = ASCII TO HEX (HEX: UPPER HALF ACC)
                    88
                    89 ;NOTE:   ASCII TO HEX CONVERSIONS ALSO TRANSMIT
                    90 ;        CHARACTER TO USRT (XMIT)
                    91
005C CD6800    C    92 ASCHEX:  CALL    DATA
005F C9             93          RET
                    94
0060 CD6800    C    95 ASCHX1:  CALL    DATA
0063 07             96          RLC
0064 07             97          RLC
0065 07             98          RLC
0066 07             99          RLC
0067 C9            100          RET
                   101
                   102 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   103 ;DATA ROUTINE HANDLES ROUTINE INPUT OF
                   104 ;HEXADECIMAL DATA IN ASCII FORMAT.
                   105 ;DATA CONVERTS TO HEX AND THEN
                   106 ;ECHOS BY CONVERTING THE HEX CODE
                   107 ;BACK INTO ASCII.
0068 C5            108 DATA:   PUSH    B
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         INPUT    PAGE    3


  LOC  OBJ          LINE        SOURCE STATEMENT

  0069 FE30          109          CPI     30H
  006B DA9500    C   110          JC      RETURN
  006E FE3A          111          CPI     3AH     ;'9' + 1
  0070 DA8900    C   112          JC      NUMBER
  0073 FE41          113          CPI     41H     ;'A'
  0075 DA9500    C   114          JC      RETURN
  0078 FE47          115          CPI     47H     ;'F' + 1
  007A DA8700    C   116          JC      LETTER
  007D FE61          117          CPI     61H     ;SMALL 'A'
  007F DA9500    C   118          JC      RETURN
  0082 FE67          119          CPI     67H     ;SMALL 'F' + 1
  0084 D29500    C   120          JNC     RETURN
  0087 C609          121 LETTER:  ADI     9
  0089 E60F          122 NUMBER:  ANI     0FH
  008B 47            123          MOV     B,A
  008C CD0000    E   124          CALL    HEX  3C
  008F CD0000    E   125          CALL    XMI,
  0092 78            126          MOV     A,B
  0093 C1            127          POP     B
  0094 C9            128          RET
                     129
                     130 ;+++++++++++++++++++++++++++++++++++++++++++++++++
  0095 C1            131 RETURN:  POP     B
  0096 F1            132          POP     PSW     ;POP RETURN ADDRESS
                     133 ;THIS RETURN ADDRESS SHOULD BE ASCHEX+3
                     134 ;OR ASCHX1+3
  0097 F1            135          POP     PSW     ;POP RETURN ADDRESS
                     136 ;THIS RETURN ADDRESS SHOULD BE = INPTXX+3
  0098 C34900    C   137          JMP     ERROR
                     138 ;HOPEFULLY INPTXX DID NOT PUSH ANYTHING
                     139
                     140
                     141          END


PUBLIC SYMBOLS
ASCHEX C 005C    ASCHX1 C 0060    ERROR  C 0049    EXIT   C 0051
INPT1  C 0030    INPUT  C 0000

EXTERNAL SYMBOLS
ATTRIB E 0000    DISP   E 0000    HEXASC E 0000    INTAD  E 0000
OPER   E 0000    PROGR  E 0000    RDPOT  E 0000    START1 E 0000
STATE  E 0000    USRT   E 0000    WAIT   E 0000    XMIT   E 0000

USER SYMBOLS
ASCHEX C 005C    ASCHX1 C 0060    ATTRIB E 0000    DATA   C 0068
DISP   E 0000    ERR    C 0014    ERROR  C 0049    EXIT   C 0051
HEXASC E 0000    INPT1  C 0030    INPUT  C 0000    INTAD  E 0000
LETTER C 0087    NUMBER C 0089    OPER   E 0000    PROGR  E 0000
RDPOT  E 0000    RETURN C 0095    START1 E 0000    STATE  E 0000
USRT   E 0000    WAIT   E 0000    XMIT   E 0000

ASSEMBLY COMPLETE,   NO ERRORS
```

```
ASCHEX    12      92#
ASCHX1    12      95#
ATTRIB    13      61
DATA      92      95      108#
DISP      13      57
ERR       29      37#      39
ERROR     11      48       65#    137
EXIT      11      67       72#
HEXASC    15     124
INPT1     11      52#
INPUT      1      11       27#
INTAD     14      77
LETTER   116     121#
NUMBER   112     122#
OPER      13      55
PROGR     13      53
RDPOT     13      59
RETURN   110     114      118     120     131#
START1    15      33
STATE     14      30       72
USRT      14      27       31      37      43      44      47
WAIT      14      46
XMIT      15      66      125

CROSS REFERENCE COMPLETE
```

```
ASM80 :F1:OPERW.ASY XREF PAGEWIDTH(72)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         OPERW    PAGE    1

  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    OPERW
                       2
                       3 ;PROGRAMMER:  C. MORRIN
                       4 ;VERSION 2.0W
                       5 ;DATE OF LAST CHANGE:  NOVEMBER 3, 1977
                       6
                       7 ;*************************************************
                       8
                       9          CSEG
                      10
                      11          PUBLIC  OPER,ATTRIB,PROMT
                      12          EXTRN   ERROR,EXIT,XMIT,INTAD
                      13          EXTRN   OPINFO,MUXAD,ASCHEX,ASCHX1
                      14          EXTRN   OUTPUT,PRADD,DISPFG,WAIT
                      15          EXTRN   GETDAT,FINAL,CUTOFF,START1
                      16          EXTRN   SETMUX,RSTART,RSTOP,DIRFLG
                      17          EXTRN   OVRFLG,DPROGM,DRSULT,COUNT
                      18          EXTRN   H0,H1,H2,H3,H4
                      19          EXTRN   H5,H6,H7,H8,H9
                      20
                      21 ;*************************************************
                      22
                      23          DSEG
                      24
                      25 ;OUTPUT MESSAGE TABLE:
0000 204F5045         26 OTAB1:   DB      ' OPER*AD='
0004 522A4144
0008 3D
0009 20474F20         27 OTAB2:   DB      ' GO = G'
000D 3D2047
0010 20324E44         28 OTAB3:   DB      ' 2ND MISS: ABORT PROG'
0014 204D4953
0018 533A2041
001C 424F5254
0020 2050524F
0024 47
0025 20464952         29 OTAB4:   DB      ' FIRST MISS'
0029 5354204D
002D 495353
0030 204F5045         30 OTAB5:   DB      ' OPER*DISP? YES OR NO'
0034 522A4449
0038 53503F20
003C 59455320
0040 4F52204E
0044 4F
0045 205B5945         31 OTAB6:   DB      ' [YES] '
0049 535D20
004C 205B4E4F         32 OTAB7:   DB      ' [NO] '
0050 5D20
                      33
0009                  34 LTAB1    EQU     9
0007                  35 LTAB2    EQU     7
0015                  36 LTAB3    EQU     21
000B                  37 LTAB4    EQU     11
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0015                38 LTAB5   EQU     21
0007                39 LTAB6   EQU     7
0006                40 LTAB7   EQU     6
                    41
                    42 ;*************************************************
                    43
                    44 ;PROM ADDRESS TABLE:
0052 0000      E    45 PROMT:  DW      H0,H1,H2,H3,H4
0054 0000      E
0056 0000      E
0058 0000      E
005A 0000      E
005C 0000      E    46         DW      H5,H6,H7,H8,H9
005E 0000      E
0060 0000      E
0062 0000      E
0064 0000      E
                    47
                    48 ;*************************************************
                    49
                    50 ;ADDRESS TABLE FOR TOOL NAMES
0066 7A00      D    51 OUTADD: DW      TOOL00,TOOL01,TOOL02,TOOL03
0068 8900      D
006A 9800      D
006C A700      D
006E B600      D    52         DW      TOOL04,TOOL05,TOOL06,TOOL07
0070 C500      D
0072 D400      D
0074 E300      D
0076 F200      D    53         DW      TOOL08,TOOL09
0078 0101      D
                    54
                    55 ;TOOL NAMES
007A 53544F57       56 TOOL00: DB      'STOW  MANIPULTR'
007E 20204D41
0082 4E495055
0086 4C5452
0089 474F2054       57 TOOL01: DB      'GO TO   TOOL #1'
008D 4F202020
0091 544F4F4C
0095 202331
0098 4D4F5645       58 TOOL02: DB      'MOVE   FROM BOX'
009C 20202046
00A0 524F4D20
00A4 424F58
00A7 474F2054       59 TOOL03: DB      'GO TO    BIT #1'
00AB 4F202020
00AF 20424954
00B3 202331
00B6 474F2054       60 TOOL04: DB      'GO TO WORK AREA'
00BA 4F20574F
00BE 524B2041
00C2 524541
00C5 53544F52       61 TOOL05: DB      'STORE    BIT #1'
00C9 45202020
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 00CD 20424954
 00D1 202331
 00D4 42495423       62 TOOL06: DB      'BIT#1 TO TOOL#1'
 00DB 3120544F
 00DC 20544F4F
 00E0 4C2331
 00E3 53544F52       63 TOOL07: DB      'STORE   TOOL #1'
 00E7 45202020
 00EB 544F4F4C
 00EF 202331
 00F2 50555348       64 TOOL08: DB      'PUSH    TOOL #1'
 00F6 20202020
 00FA 544F4F4C
 00FE 202331
 0101 54525920       65 TOOL09: DB      'TRY       AGAIN'
 0105 20202020
 0109 20204147
 010D 41494E
                     66
                     67 ;************************************************
                     68
                     69 ;LINKAGE MANIPULATOR INTERFACE ROUTINE
                     70
                     71 ;THIS ROUTINE OPERATES SOLENOID VALVES ONLY
                     72 ;THERE IS NO PROVISION FOR MULTIPLE VALVE
                     73 ;OPERATION
                     74 ;(WILL NOT OPERATE WSP LINEAR EXTEND)
                     75
                     76 ;THIS ROUTINE DOES THE FOLLOWING:
                     77 ;1. DETERMINE WHETHER ARM IS WITHIN DEADBAND,
                     78 ;   ABOVE DEADBAND, OR BELOW DEADBAND.
                     79 ;2. IF WITHIN DEADBAND, CHANGE PROGRAM COUNTER,
                     80 ;   AND GO TO STEP 1.
                     81 ;3. IF OUTSIDE DEADBAND, STORE SHUTOFF POSITION
                     82 ;   IN REG BC, TURN ON APPROPRIATE SOLENOID AND
                     83 ;   COMPARE A/D DATA TO REG BC.
                     84 ;   WHEN SHUTOFF POSITION IS REACHED,
                     85 ;   TURN OFF ALL SOLENOIDS.
                     86 ;4. WAIT FOR AN APPROPRIATE PERIOD,
                     87 ;   THEN CHECK AGAIN.
                     88 ;5. IF OTAB3OGT OCCURS, TRY ONCE MORE.
                     89 ;6. IF A SECOND OTAB3OOT OCCURS, OPERATOR IS
                     90 ;   NOTIFIED AND OPERATION ABORTED.
                     91 ;7. IF WITHIN DEADBAND, DISPLAY RESULTS.
                     92 ;8. CHECK FOR END OF PROGRAM, AND EITHER
                     93 ;   INCREMENT PROGRAM OR STOP.
                     94
                     95          CSEG
                     96
                     97 ;++++++++++++++++++++++++++++++++++++++++++++++++
                     98 ;OPERATE MODE, REQUEST ADDRESS INFORMATION:
 0000 210000    D    99 OPER:    LXI     H,OTAB1 ;'OPERATE ADDRESS='
 0003 0E09          100         MVI     C,LTAB1
 0005 CD0000    E   101         CALL    OUTPUT
 0008 210E00    C   102         LXI     H,OPER1  ;CALL OPER1 NEXT
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

000B C30000   E    103          JMP     EXIT
                   104
                   105 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   106 ;OPERATE MODE, FIRST ADDRESS DIGIT
000E 320100   E    107 OPER1:   STA     OPINFO+1
0011 FE2A          108          CPI     '*'
0013 CA2700   C    109          JZ      EPROM
0016 CD0000   E    110          CALL    ASCHX1
0019 320000   E    111          STA     PRADD
001C 3EF1          112          MVI     A,0F1H
001E 320100   E    113          STA     PRADD+1
0021 213000   C    114          LXI     H,OPER2
0024 C30000   E    115          JMP     EXIT
                   116
                   117 ;+++++++++++++++++++++++++++++++++++++++++++++++++
0027 CD0000   E    118 EPROM:   CALL    XMIT    ;ECHO
002A 216600   C    119          LXI     H,OPER4
002D C30000   E    120          JMP     EXIT
                   121
                   122 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   123 ;OPERATE MODE, SECOND ADDRESS DIGIT
0030 320200   E    124 OPER2:   STA     OPINFO+2
0033 CD0000   E    125          CALL    ASCHEX
0036 210000   E    126          LXI     H,PRADD
0039 B6            127          ORA     M
003A 77            128          MOV     M,A
                   129 ;OPERATE ADDRESS STORED IN PRADD IN BINARY
003B 210900   D    130 GO:      LXI     H,OTAB2
003E 0E07          131          MVI     C,LTAB2
0040 CD0000   E    132          CALL    OUTPUT  ;' GO=G'
0043 214900   C    133 GO1:     LXI     H,OPER3
0046 C30000   E    134          JMP     EXIT
                   135
                   136 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   137 ;OPERATE MODE, FIRST "GO" COMMAND
0049 FE53          138 OPER3:   CPI     'S'
004B CA0000   E    139          JZ      START1
004E FE47          140          CPI     'G'
0050 C26000   C    141          JNZ     TSTOP
                   142 ;OPERATE MANIPULATOR, BUT FIRST ENABLE
                   143 ;HAND CONTROLLER (EMERGENCY STOP)
0053 F3            144          DI
0054 3E65          145          MVI     A,65H
                   146 ;OCW2: END OF INPUT INTERRUPT
0056 320000   E    147          STA     INTAD
0059 FB            148          EI
005A CDDD00   C    149          CALL    OPERAT
005D C30000   C    150          JMP     OPER
                   151
                   152 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   153 ;EMERGENCY STOP IF OPERATING,
                   154 ;ERROR MESSAGE IF NOT:
0060 CD0000   E    155 TSTOP:   CALL    RSTOP
0063 C30000   E    156          JMP     ERROR
                   157
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

                    158 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    159 ;HARDWIRED PROGRAM MODE, ADDRESS DIGIT
 0066 320200    E   160 OPER4:  STA     OPINFO+2
 0069 CD0000    E   161         CALL    ASCHEX
 006C 07            162         RLC
 006D 5F            163         MOV     E,A     ;SAVE DIGIT X 2
 006E 4F            164         MOV     C,A
 006F 0600          165         MVI     B,0
 0071 215200    D   166         LXI     H,PROMT
 0074 09            167         DAD     B
                    168 ;REG H = PROGRAM ADDRESS
 0075 7E            169         MOV     A,M     ;GET ADDRESS
 0076 320000    E   170         STA     PRADD   ;PUT IT AWAY
 0079 23            171         INX     H
 007A 7E            172         MOV     A,M     ;GET 2ND HALF
 007B 320100    E   173         STA     PRADD+1 ;PUT IT AWAY
                    174 ;OUTPUT NAME OF TOOL REQUESTED:
 007E 210000    E   175         LXI     H,OPINFO
 0081 0E04          176         MVI     C,4
 0083 CD0000    E   177         CALL    OUTPUT  ;' *A '
 0086 3E3D          178         MVI     A,'='
 0088 CD0000    E   179         CALL    XMIT
 008B 3E20          180         MVI     A,' '
 008D CD0000    E   181         CALL    XMIT
 0090 216600    D   182         LXI     H,OUTADD
 0093 1600          183         MVI     D,0     ;E CONTAINS DIGIT X 2
 0095 19            184         DAD     D
                    185 ;REG H = OUTPUT ADDRESS
 0096 5E            186         MOV     E,M
 0097 23            187         INX     H
 0098 56            188         MOV     D,M
 0099 EB            189         XCHG
 009A 0E0F          190         MVI     C,15
 009C CD0000    E   191         CALL    OUTPUT
 009F C34300    C   192         JMP     GO1
                    193
                    194 ;***********************************************
                    195
 00A2 213000    D   196 ATTRIB: LXI     H,OTAB5
 00A5 0E15          197         MVI     C,LTAB5
 00A7 CD0000    E   198         CALL    OUTPUT  ;' OPER*DISP YES OR NO'
 00AA 21B000    C   199         LXI     H,OPER10
 00AD C30000    E   200         JMP     EXIT
                    201
                    202 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    203 ;DISPLAY DIAGNOSTICS DURING OPERATION?
 00B0 FE59          204 OPER10: CPI     'Y'
 00B2 CABD00    C   205         JZ      AYES
 00B5 FE4E          206         CPI     'N'
 00B7 CACD00    C   207         JZ      ANO
 00BA C30000    E   208         JMP     ERROR
                    209
                    210 ;+++++++++++++++++++++++++++++++++++++++++++++++++
 00BD 214500    D   211 AYES:   LXI     H,OTAB6
 00C0 0E07          212         MVI     C,LTAB6
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

00C2 CD0000   E    213          CALL     OUTPUT  ;' YES'
00C5 3E0F          214          MVI      A,0FH
00C7 320000   E    215          STA      DISPFG
00CA C30000   E    216          JMP      START1
                   217
                   218 ;+++++++++++++++++++++++++++++++++++++++++++++++++
00CD 214C00   D    219 ANO:     LXI      H,OTAB7
00D0 0E06          220          MVI      C,LTAB7
00D2 CD0000   E    221          CALL     OUTPUT  ;' NO'
00D5 3E00          222          MVI      A,0
00D7 320000   E    223          STA      DISPFG
00DA C30000   E    224          JMP      START1
                   225
                   226 ;*************************************************
                   227
                   228 ;INTIALIZE MULTIPLEXER
00DD 2A0000   E    229 OPERAT: LHLD     PRADD   ;CHECK FOR HAND
00E0 7E            230          MOV      A,M
00E1 E60E          231          ANI      0EH     ;MASK
00E3 FE08          232          CPI      8
00E5 CAE601   C    233          JZ       HAND
00E8 FE0E          234          CPI      0EH
00EA CAE601   C    235          JZ       HAND
00ED CD0000   E    236          CALL     SETMUX  ;SET MUX & WAIT 100 MS
00F0 3A0000   E    237          LDA      DISPFG
00F3 E60F          238          ANI      0FH     ;SET ZERO FLAG
00F5 CAFB00   C    239          JZ       SKIP1
00F8 CD0000   E    240          CALL     DPROGM
                   241
                   242 ;IS DATA LARGER THAN POSITION + DEADBAND ?
00FB CD0002   C    243 SKIP1:   CALL     GETBC   ;BC = -(POS+DB)
00FE CD0000   E    244          CALL     GETDAT  ;HL = A/D DATA
0101 09            245          DAD      B
0102 DA3701   C    246          JC       ABOVE
                   247
                   248 ;IS DATA SMALLER THAN POSITION - DEADBAND ?
0105 CD1A02   C    249          CALL     GETBCM  ;BC = -(POS-DB)
0108 2A0000   E    250          LHLD     MUXAD   ;DATA FROM PREVIOUS GETD
                        AT
010B 09            251          DAD      B       ;HL = A/D-(POS-DB)
010C D27301   C    252          JNC      BELOW
010F 2A0000   E    253          LHLD     MUXAD   ;WITHIN DEADBAND
0112 220000   E    254          SHLD     CUTOFF  ;CUTOFF=FINAL
0115 220000   E    255          SHLD     FINAL
                   256
                   257 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   258 ;END OF OPERAT ROUTINE:
                   259 ;DISPLAY RESULTS, INCREMENT PROGRAM ADDRESS &
                   260 ;DETERMINE IF END OF PROGRAM HAS BEEN REACHED.
0118 3E00          261 ENDOP:   MVI      A,0
011A 320000   E    262          STA      OVRFLG
011D 3A0000   E    263          LDA      DISPFG
0120 E60F          264          ANI      0FH     ;SET ZERO FLAG
0122 CA2801   C    265          JZ       SKIP2
0125 CD0000   E    266          CALL     DRSULT
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0128 2A0000   E    267 SKIP2:  LHLD    PRADD   ;GET PROGRAM ADDRESS
012B 110400        268         LXI     D,4     ;INCREMENT PROGRAM
012E 19            269         DAD     D
012F 220000   E    270         SHLD    PRADD
0132 7E            271         MOV     A,M
0133 E6F0          272         ANI     0F0H    ;GET END OF PROGRAM FLAG
0135 C0            273         RNZ
0136 C3DD00   C    274         JMP     OPERAT
                   275
                   276 ;+++++++++++++++++++++++++++++++++++++++++++++++
                   277 ;OPERATE MANIPULATOR: A/D DATA IS LARGER.
0139 3E01          278 ABOVE:  MVI     A,1
013B 320000   E    279         STA     DIRFLG
013E CD0000   E    280         CALL    RSTART
0141 CD3602   C    281         CALL    RUN
0144 CD0000   E    282         CALL    RSTOP
0147 2A0000   E    283         LHLD    MUXAD
014A 220000   E    284         SHLD    CUTOFF  ;SAVE FOR DRSULT
                   285
                   286 ;OPERATION COMPLETE, WAIT FOR ARM TO STOP
014D 011027        287         LXI     B,10000 ;WAIT .5 SECOND
0150 CD0000   E    288         CALL    WAIT
                   289
                   290 ;CHECK FOR BAD POT READING:
0153 CD0002   C    291         CALL    GETBC
0156 21F0FF        292         LXI     H,0FFF0H
0159 09            293         DAD     B
015A 44            294         MOV     B,H
015B 4D            295         MOV     C,L
015C CD0000   E    296         CALL    GETDAT
015F 09            297         DAD     B
0160 DADD00   C    298         JC      OPERAT
                   299
                   300 ;IF OK, CHECK FOR OVERSHOOT:
0163 CD1A02   C    301         CALL    GETBCM  ;BC = -(POS-DB)
0166 CD0000   E    302         CALL    GETDAT  ;HL = A/D DATA
0169 220000   E    303         SHLD    FINAL   ;SAVE FOR DRSULT
016C 09            304         DAD     B       ;HL = A/D-(POS-DB)
016D D2AD01   C    305         JNC     OVRSHT
                   306
                   307 ;MANIPULATOR IS WITHIN DEADBAND.
0170 C31801   C    308         JMP     ENDOP
                   309
                   310 ;+++++++++++++++++++++++++++++++++++++++++++++++
                   311 ;OPERATE MANIPULATOR: A/D DATA SMALLER.
0173 3E00          312 BELOW:  MVI     A,0
0175 320000   E    313         STA     DIRFLG
0178 CD0000   E    314         CALL    RSTART
017B CD6502   C    315         CALL    RUNM
017E CD0000   E    316         CALL    RSTOP
0181 2A0000   E    317         LHLD    MUXAD
0184 220000   E    318         SHLD    CUTOFF
                   319
                   320 ;OPERATION COMPLETE, WAIT FOR ARM TO STOP
0187 011027        321         LXI     B,10000 ;WAIT .5 SECONDS
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

018A CD0000   E    322          CALL    WAIT
                   323
                   324 ;CHECK FOR BAD POT READING:
018D CD1A02   C    325          CALL    GETBCM
0190 211000        326          LXI     H,0010H
0193 09            327          DAD     B
0194 44            328          MOV     B,H
0195 4D            329          MOV     C,L
0196 CD0000   E    330          CALL    GETDAT
0199 09            331          DAD     B
019A D2DD00   C    332          JNC     OPERAT
                   333
                   334 ;IF OK, CHECK FOR OVERSHOOT:
019D CD0002   C    335          CALL    GETBC    ;BC = -(POS+DB)
01A0 CD0000   E    336          CALL    GETDAT   ;HL = A/D DATA
01A3 220000   E    337          SHLD    FINAL    ;SAVE FOR DRSULT
01A6 09            338          DAD     B        ;HL = A/D - (POS+DB)
01A7 DAAD01   C    339          JC      OVRSHT
                   340
                   341 ;MANIPULATOR IS WITHIN DEADBAND.
01AA C31B01   C    342          JMP     ENDOP
                   343
                   344 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   345 ;MANIPULATOR MISSED DEADBAND REGION
01AD 3A0000   E    346 OVRSHT: LDA     OVRFLG
01B0 E6FF          347          ANI     0FFH
01B2 C2B301   C    348          JNZ     OVRSH1
                   349
                   350 ;MISSED ON FIRST ATTEMPT, NOTIFY
                   351 ;OPERATOR AND TRY AGAIN
01B5 3E01          352          MVI     A,1
01B7 320000   E    353          STA     OVRFLG
01BA 3A0000   E    354          LDA     DISPFG
01BD E60F          355          ANI     0FH
01BF CADD00   C    356          JZ      OPERAT
01C2 CD0000   E    357          CALL    DPROGM
01C5 CD0000   E    358          CALL    DRSULT
01C8 212500   D    359          LXI     H,OTAB4
01CB 0E0B          360          MVI     C,LTAB4
01CD CD0000   E    361          CALL    OUTPUT   ;' FIRST MISS'
01D0 C3DD00   C    362          JMP     OPERAT
                   363
                   364 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   365 ;MANIPULATOR HAS MISSED TWICE,
                   366 ;ABORT OPERATION
01D3 3600          367 OVRSH1: MVI     M,0
01D5 CD0000   E    368          CALL    DPROGM
01D8 CD0000   E    369          CALL    DRSULT
01DB 211000   D    370          LXI     H,OTAB3
01DE 0E15          371          MVI     C,LTAB3
01E0 CD0000   E    372          CALL    OUTPUT   ;'2ND MISS:  ABORT PROG'
01E3 C30000   E    373          JMP     START1
                   374
                   375 ;+++++++++++++++++++++++++++++++++++++++++++++++++
01E6 3A0000   E    376 HAND:   LDA     DISPFG
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 01E9 E60F          377         ANI     0FH
 01EB CAF101    C   378         JZ      SKIP3
 01EE CD0000    E   379         CALL    DPROGM
 01F1 CD0000    E   380 SKIP3:  CALL    RSTART
 01F4 01FFFF        381         LXI     B,0FFFFH
 01F7 CD0000    E   382         CALL    WAIT    ;WAIT 3 SEC
 01FA CD0000    E   383         CALL    RSTOP
 01FD C32B01    C   384         JMP     SKIP2
                    385
                    386 ;*************************************************
                    387
 0200 2A0000    E   388 GETBC:  LHLD    PRADD
 0203 23            389         INX     H       ;(REG HL) = DATA (HIGH)
 0204 46            390         MOV     B,M
 0205 23            391         INX     H
 0206 4E            392         MOV     C,M
 0207 23            393         INX     H       ;(REG HL) = DEADBAND
 0208 5E            394         MOV     E,M
 0209 1600          395         MVI     D,0     ;DE = DEADBAND
                    396 ;DEADBAND HAS TO BE SHIFTED 4 PLACES:
 020B EB            397         XCHG
 020C 29            398         DAD     H       ;LEFT SHIFT REG HL
 020D 29            399         DAD     H
 020E 29            400         DAD     H
 020F 29            401         DAD     H
 0210 09            402         DAD     B       ;HL = POS+DB
                    403         ;A CARRY HERE IS AN ERROR
 0211 3E00          404         MVI     A,0
 0213 95            405         SUB     L
 0214 4F            406         MOV     C,A
 0215 3E00          407         MVI     A,0
 0217 9C            408         SBB     H
 0218 47            409         MOV     B,A     ;BC = -(POS+DB)
 0219 C9            410         RET
                    411
                    412 ;*************************************************
                    413
 021A 2A0000    E   414 GETBCM: LHLD    PRADD
 021D 23            415         INX     H
 021E 23            416         INX     H
 021F 3E00          417         MVI     A,0
 0221 96            418         SUB     M
 0222 4F            419         MOV     C,A
 0223 2B            420         DCX     H
 0224 3E00          421         MVI     A,0
 0226 9E            422         SBB     M
 0227 47            423         MOV     B,A     ;BC = -POS
 0228 23            424         INX     H
 0229 23            425         INX     H
 022A 5E            426         MOV     E,M
 022B 1600          427         MVI     D,0
 022D EB            428         XCHG            ;HL = DB/4
 022E 29            429         DAD     H
 022F 29            430         DAD     H
 0230 29            431         DAD     H
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 0231 29            432         DAD     H       ;HL = DB
 0232 09            433         DAD     B       ;HL = -(POS-DB)
 0233 44            434         MOV     B,H
 0234 4D            435         MOV     C,L
 0235 C9            436         RET             ;BC = -(POS-DB)
                    437
                    438 ;***********************************************
                    439 ;*        REAL TIME OPERATION ROUTINES         *
                    440 ;***********************************************
                    441
                    442 ;REG B = POSITION INFORMATION
                    443 ;REG D = ADDRESS OF SINGLE BIT COMMAND FOR A/D
                    444 ;REG H = A/D DATA & DIFFERENCE
                    445
 0236 110300    E   446 RUN:    LXI     D,MUXAD+3
 0239 3E00          447         MVI     A,0
 023B 320000    E   448         STA     COUNT
 023E 3E01          449 RUN1:   MVI     A,1
                    450
                    451 ;SET A/D START BIT HIGH:
 0240 12            452         STAX    D       ;(7 CYCLES)
 0241 3D            453         DCR     A       ;(5 CYCLES)
                    454
                    455 ;A/D CONVERTER READY, GET DATA:
 0242 2A0000    E   456         LHLD    MUXAD
                    457 ;PRIOR TO DATA READ:     (10 CYCLES)
                    458 ;TIME TO READ DATA:      (6 CYCLES)
                    459
                    460 ;RESET A/D START BIT LOW (STARTS A/D)
 0245 12            461         STAX    D       ;(7 CYCLES)
 0246 09            462         DAD     B       ;(10 CYCLES)
 0247 DA5702    C   463         JC      CNTDN   ;(10 CYCLES)
 024A 3A0000    E   464         LDA     COUNT
 024D 3C            465         INR     A
 024E 320000    E   466         STA     COUNT
 0251 FE0A          467         CPI     10
 0253 C23E02    C   468         JNZ     RUN1
 0256 C9            469         RET
 0257 3A0000    E   470 CNTDN:  LDA     COUNT
 025A 3D            471         DCR     A
 025B D25F02    C   472         JNC     CNTDN1
 025E 97            473         SUB     A       ;DONT WANT MINUS NUMBERS
 025F 320000    E   474 CNTDN1: STA     COUNT
 0262 C33E02    C   475         JMP     RUN1
                    476
                    477 ;DATA READ TIME:  13 CYCLES OR 7 MICROSECONDS
                    478
                    479 ;CONVERSION TIME: 47 CYCLES OR 23 MICROSECONDS
                    480
                    481 ;TOTAL TIME:      60 CYCLES OR 30 MICROSECONDS
                    482
                    483 ;***********************************************
                    484
 0265 110300    E   485 RUNM:   LXI     D,MUXAD+3
 0268 3E00          486         MVI     A,0
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 026A 320000   E    487          STA     COUNT
 026D 3E01          488 RUNM1:   MVI     A,1
 026F 12            489          STAX    D
 0270 3D            490          DCR     A
 0271 2A0000   E    491          LHLD    MUXAD
 0274 12            492          STAX    D
 0275 09            493          DAD     B
 0276 D2B602   C    494          JNC     CNTDNM
 0279 3A0000   E    495          LDA     COUNT
 027C 3C            496          INR     A
 027D 320000   E    497          STA     COUNT
 0280 FE0A          498          CPI     10
 0282 C26D02   C    499          JNZ     RUNM1
 0285 C9            500          RET
 0286 3A0000   E    501 CNTDNM:  LDA     COUNT
 0289 3D            502          DCR     A
 028A D28E02   C    503          JNC     CNT1
 028D 97            504          SUB     A
 028E 320000   E    505 CNT1:    STA     COUNT
 0291 C36D02   C    506          JMP     RUNM1
 0294 C9            507          RET
                    508
                    509 ;*************************************************
                    510 ;*      END REAL TIME OPERATION ROUTINES         *
                    511 ;*************************************************
                    512
                    513          END
```

```
PUBLIC SYMBOLS
ATTRIB C 00A2    OPER   C 0000    PROMT  D 0052

EXTERNAL SYMBOLS
ASCHEX E 0000    ASCHX1 E 0000    COUNT  E 0000    CUTOFF E 0000
DIRFLG E 0000    DISPFG E 0000    DPROGM E 0000    DRSULT E 0000
ERROR  E 0000    EXIT   E 0000    FINAL  E 0000    GETDAT E 0000
H0     E 0000    H1     E 0000    H2     E 0000    H3     E 0000
H4     E 0000    H5     E 0000    H6     E 0000    H7     E 0000
H8     E 0000    H9     E 0000    INTAD  E 0000    MUXAD  E 0000
OPINFO E 0000    OUTPUT E 0000    OVRFLG E 0000    PRADD  E 0000
RSTART E 0000    RSTOP  E 0000    SETMUX E 0000    START1 E 0000
WAIT   E 0000    XMIT   E 0000

USER SYMBOLS
ABOVE  C 0139    ANO    C 00CD    ASCHEX E 0000    ASCHX1 E 0000
ATTRIB C 00A2    AYES   C 00BD    BELOW  C 0173    CNT1   C 028E
CNTDN  C 0257    CNTDN1 C 025F    CNTDNM C 0286    COUNT  E 0000
CUTOFF E 0000    DIRFLG E 0000    DISPFG E 0000    DPROGM E 0000
DRSULT E 0000    ENDOP  C 0118    EPROM  C 0027    ERROR  E 0000
EXIT   E 0000    FINAL  E 0000    GETBC  C 0200    GETBCM C 021A
GETDAT E 0000    GO     C 003B    GO1    C 0043    H0     E 0000
H1     E 0000    H2     E 0000    H3     E 0000    H4     E 0000
H5     E 0000    H6     E 0000    H7     E 0000    H8     E 0000
H9     E 0000    HAND   C 01E6    INTAD  E 0000    LTAB1  A 0009
LTAB2  A 0007    LTAB3  A 0015    LTAB4  A 000B    LTAB5  A 0015
```

```
LTAB6   A 0007    LTAB7   A 0006    MUXAD   E 0000    OPER    C 0000
OPER1   C 000E    OPER10  C 00B0    OPER2   C 0030    OPER3   C 0049
OPER4   C 0066    OPERAT  C 00DD    OPINFO  E 0000    OTAB1   D 0000
OTAB2   D 0009    OTAB3   D 0010    OTAB4   D 0025    OTAB5   D 0030
OTAB6   D 0045    OTAB7   D 004C    OUTADD  D 0066    OUTPUT  E 0000
OVRFLG  E 0000    OVRSH1  C 01D3    OVRSHT  C 01AD    PRADD   E 0000
PROMT   D 0052    RSTART  E 0000    RSTOP   E 0000    RUN     C 0236
RUN1    C 023E    RUNM    C 0265    RUNM1   C 026D    SETMUX  E 0000
SKIP1   C 00FB    SKIP2   C 0128    SKIP3   C 01F1    START1  E 0000
TOOL00  D 007A    TOOL01  D 0089    TOOL02  D 0098    TOOL03  D 00A7
TOOL04  D 00B6    TOOL05  D 00C5    TOOL06  D 00D4    TOOL07  D 00E3
TOOL08  D 00F2    TOOL09  D 0101    TSTOP   C 0060    WAIT    E 0000
XMIT    E 0000

ASSEMBLY COMPLETE,  NO ERRORS
```

```
ABOVE    246    278#
AND      207    219#
ASCHEX    13    125     161
ASCHX1    13    110
ATTRIB    11    196#
AYES     205    211#
BELOW    252    312#
CNT1     503    505#
CNTDN    463    470#
CNTDN1   472    474#
CNTDNM   494    501#
COUNT     17    448     464     466     470     474     487     495     497
         501    505
CUTOFF    15    254     284     318
DIRFLG    16    279     313
DISPFG    14    215     223     237     263     354     376
DPROGM    17    240     357     368     379
DRSULT    17    266     358     369
ENDOP   261#    308     342
EPROM    109    118#
ERROR     12    156     208
EXIT      12    103     115     120     134     200
FINAL     15    255     303     337
GETBC    243    291     335     388#
GETBCM   249    301     325     414#
GETDAT    15    244     296     302     330     336
GO       130#
GO1      133#    192
H0        18     45
H1        18     45
H2        18     45
H3        18     45
H4        18     45
H5        19     46
H6        19     46
H7        19     46
H8        19     46
H9        19     46
HAND     233    235     376#
INTAD     12    147
LTAB1    34#    100
LTAB2    35#    131
LTAB3    36#    371
LTAB4    37#    360
LTAB5    38#    197
LTAB6    39#    212
LTAB7    40#    220
MUXAD     13    250     253     283     317     446     456     485     491
OPER      11     99#    150
OPER1    102    107#
OPER10   199    204#
OPER2    114    124#
OPER3    133    138#
OPER4    119    160#
OPERAT   149    229#    274     298     332     356     362
OPERW      1
OPINFO    13    107     124     160     175
```

```
OTAB1     26#    99
OTAB2     27#   130
OTAB3     28#   370
OTAB4     29#   359
OTAB5     30#   196
OTAB6     31#   211
OTAB7     32#   219
OUTADD    51#   182
OUTPUT    14     101    132    177    191    198    213    221    361
          372
OVRFLG    17     262    346    353
OVRSH1   348     367#
OVRSHT   305     339    346#
PRADD     14     111    113    126    170    173    229    267    270
          388     414
PRONT     11      45#   166
RSTART    16     280    314    380
RSTOP     16     155    282    316    383
RUN      281     446#
RUN1     449#    468    475
RUNM     315     485#
RUNM1    488#    499    506
SETMUX    16     236
SKIP1    239     243#
SKIP2    265     267#   384
SKIP3    378     380#
START1    15     139    216    224    373
TOOL00    51      56#
TOOL01    51      57#
TOOL02    51      58#
TOOL03    51      59#
TOOL04    52      60#
TOOL05    52      61#
TOOL06    52      62#
TOOL07    52      63#
TOOL08    53      64#
TOOL09    53      65#
TSTOP    141     155#
WAIT      14     288    322    382
XMIT      12     118    179    181
```

CROSS REFERENCE COMPLETE

```
ASM80 :F1:OUTPUT.ASY XREF PAGEWIDTH(72)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         OUTPUT   PAGE    1


  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    OUTPUT
                       2
                       3 ;PROGRAMMER:  C.MORRIN
                       4 ;VERSION 2.0
                       5 ;DATE OF LAST CHANGE:  OCTOBER 31, 1977
                       6
                       7 ;*************************************************
                       8
                       9          CSEG
                      10
                      11          PUBLIC  DISP,XMIT,HEXASC,HXASC1
                      12          PUBLIC  OUTPUT,DPROGM,DRSULT,FNASC
                      13          EXTRN   WAIT,EXIT,ASCHEX,ASCHX1
                      14          EXTRN   USRT,OPINFO,PRADD,FINAL
                      15          EXTRN   CUTOFF,ERROR,SAVE,START1
                      16          EXTRN   PRONT,STOPFG
                      17
                      18 ;*************************************************
                      19
                      20          DSEG
                      21
0000 2046494E         22 ODATA1: DB       ' FINAL='
0004 414C3D
0007 20444946         23 ODATA2: DB       ' DIFF=='
000B 463D3D
000E 20505247         24 ODATA3: DB       ' PRGM*AD='
0012 4D2A4144
0016 3D
0017 2043544F         25 ODATA4: DB       ' CTOFF='
001B 46463D
001E 20444953         26 ODATA5: DB       ' DISP*AD='
0022 502A4144
0026 3D
0027 20235354         27 ODATA6: DB       ' #STEPS='
002B 4550533D
002F 2053544F         28 ODATA7: DB       ' STOP '
0033 5020
                      29
0007                  30 LDATA1  EQU      7
0007                  31 LDATA2  EQU      7
0009                  32 LDATA3  EQU      9
0007                  33 LDATA4  EQU      7
0009                  34 LDATA5  EQU      9
0008                  35 LDATA6  EQU      8
0006                  36 LDATA7  EQU      6
                      37
                      38 ;*************************************************
                      39
                      40 ;DISPLAY PROGRAM ROUTINE:
                      41
                      42 ;INPUT INTERFACE:
                      43 ;DISPLAY MODE, REQUEST ADDRESS INFORMATION:
0035 211E00    D      44 DISP:   LXI      H,ODATA5
0038 0E09             45          MVI     C,LDATA5
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

003A CDCF00   D     46          CALL    OUTPUT    ;' DISP*AD='
                    47 ;INITIALIZE PRADD:
003D 3EF1           48          MVI     A,0F1H
003F 320100   E     49          STA     PRADD+1
0042 214800   D     50          LXI     H,DISP1   ;CALL DISP1 NEXT
0045 C30000   E     51          JMP     EXIT
                    52
                    53 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    54 ;DISPLAY MODE, FIRST ADDRESS DIGIT
0048 FE2A           55 DISP1:   CPI     '*'
004A CA5C00   D     56          JZ      DISP2
004D 320100   E     57          STA     OPINFO+1
0050 CD0000   E     58          CALL    ASCHX1
0053 320000   E     59          STA     PRADD
0056 217E00   D     60          LXI     H,DISP3
0059 C30000   E     61          JMP     EXIT
                    62
                    63 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    64 ;DISPLAY HARDWIRED MEMORY, CHANGE PRADD:
005C CDBF00   D     65 DISP2:   CALL    XMIT
005F 216500   D     66          LXI     H,DISP2A
0062 C30000   E     67          JMP     EXIT
                    68
                    69 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    70 ;HARDWIRED MODE, 2ND ADDRESS DIGIT:
0065 CD0000   E     71 DISP2A:  CALL    ASCHEX
0068 07             72          RLC
0069 4F             73          MOV     C,A
006A 0600           74          MVI     B,0
006C 210000   E     75          LXI     H,PROMT
006F 09             76          DAD     B
                    77 ;(REG H) CONTAINS STARTING ADDRESS
                    78 ;GET STARTING ADDRESS:
0070 5E             79          MOV     E,M
0071 23             80          INX     H
0072 56             81          MOV     D,M
                    82 ;STORE STARTING ADDRESS IN PRADD:
0073 210000   E     83          LXI     H,PRADD
0076 73             84          MOV     M,E
0077 23             85          INX     H
0078 72             86          MOV     M,D
0079 061F           87          MVI     B,1FH
007B C39A00   D     88          JMP     D4
                    89
                    90 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    91 ;DISPLAY MODE, SECOND ADDRESS DIGIT
007E 320200   E     92 DISP3:   STA     OPINFO+2
0081 CD0000   E     93          CALL    ASCHEX
0084 210000   E     94          LXI     H,PRADD
0087 B6             95          ORA     M
0088 77             96          MOV     M,A       ;PRADD NOW CONTAINS
                    97 ;ADDRESS OF FIRST PROGRAM STEP TO BE DISPLAYED
0089 212700   D     98          LXI     H,ODATA6
008C 0E08           99          MVI     C,LDATA6
008E CDCF00   D    100          CALL    OUTPUT    ;' #STEPS='
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

0091 219700   D    101          LXI     H,DISP4
0094 C30000   E    102          JMP     EXIT
                   103
                   104 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   105 ;DISPLAY MODE, NUMBER OF STEPS
                   106 ;DPROGM (OUTPUT MODULE) IS MAIN ROUTINE
                   107 ;FOR DISPLAY MODE.  IT REQUIRES ADDRESS
                   108 ;IN PRADD.
0097 CD0000   E    109 DISP4:  CALL    ASCHEX
009A 47            110 D4:     MOV     B,A
009B CDEC00   D    111         CALL    DPROGM
009E C5            112         PUSH    B
009F 01204E        113         LXI     B,20000
00A2 CD0000   E    114         CALL    WAIT     ;DISPLAY 1 SEC
00A5 C1            115         POP     B
00A6 2A0000   E    116         LHLD    PRADD
00A9 110400        117         LXI     D,4
00AC 19            118         DAD     D
00AD 220000   E    119         SHLD    PRADD
00B0 3A0000   E    120         LDA     STOPFG
00B3 E6FF          121         ANI     OFFH     ;SET FLAGS
00B5 C20000   E    122         JNZ     START1
                   123 ;"STOP" FUNCTION HAS BEEN DISPLAYED
00B8 05            124         DCR     B
00B9 C29B00   D    125         JNZ     DISP4+4
00BC C30000   E    126         JMP     START1
                   127
                   128 ;*************************************************
                   129
                   130 ;TRANSMIT CHARACTER ROUTINE:
                   131 ;CHARACTER MUST BE IN ACC
                   132
00BF C5            133 XMIT:   PUSH    B
00C0 47            134         MOV     B,A
00C1 3A0100   E    135 XMIT1:  LDA     USRT+1   ;GET USRT STATUS
00C4 E601          136         ANI     1        ;GET TXRDY BIT
00C6 CAC100   D    137         JZ      XMIT1    ;READY?
00C9 78            138         MOV     A,B      ;YES
00CA 320000   E    139         STA     USRT
00CD C1            140         POP     B
00CE C9            141         RET
                   142
                   143 ;*************************************************
                   144
                   145 ;OUTPUT ROUTINE
                   146
                   147 ;THIS ROUTINE OUTPUTS A BLOCK OF DATA
                   148 ;TO A 8251 USRT.
                   149 ;OUTPUT REQUIRES THE FOLLOWING:
                   150 ;REG HL MUST CONTAIN BEGINNING ADDRESS OF DATA.
                   151 ;REG C MUST CONTAIN LENGTH OF DATA BLOCK.
                   152 ;DATA MUST BE IN ASCII FORMAT.
                   153
00CF F5            154 OUTPUT: PUSH    PSW
00D0 7E            155         MOV     A,M      ;GET NEXT CHARACTER
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

00D1 CDBF00    D   156          CALL    XMIT    ;TRANSMIT IT
00D4 23            157          INX     H
00D5 0D            158          DCR     C
00D6 C2D000    D   159          JNZ     OUTPUT+1  ;MORE CHARACTERS?
00D9 F1            160          POP     PSW
00DA C9            161          RET
                   162
                   163 ;*************************************************
                   164
                   165 ;HEXADECIMAL TO ASCII CONVERSION ROUTINES:
                   166 ;ALL ROUTINES START AND END WITH DATA IN ACC
                   167 ;HEXASC = HEX TO ASCII (HEX: LOWER HALF ACC)
                   168 ;HXASC1 = HEX TO ASCII (HEX: UPPER HALF ACC)
                   169
00DB 0F            170 HXASC1: RRC
00DC 0F            171         RRC
00DD 0F            172         RRC
00DE 0F            173         RRC
00DF E60F          174 HEXASC: ANI     0FH
00E1 FE0A          175         CPI     10
00E3 D2E900    D   176         JNC     HEX1
00E6 F630          177         ORI     30H
00E8 C9            178         RET
00E9 C637          179 HEX1:   ADI     37H
00EB C9            180         RET
                   181
                   182 ;*************************************************
                   183
                   184 ;DISPLAY PROGRAM STEP ROUTINE
                   185
                   186 ;THIS PROGRAM USES THE PROGRAM POINTER PRADD
                   187 ;AS AN INPUT.  THE OUTPUT IS THE CONTENTS OF
                   188 ;PRADD, AND THE CONTENTS OF THE INSTRUCTION
                   189 ;POINTED TO BY PRADD.
                   190
                   191 ;THE FORMAT OF THE OUTPUT IS:
                   192 ;   'PROG*AD=XX'
                   193 ;   'FN-DATA-DB'
                   194 ;WHERE  XX = CONTENTS OF PRADD
                   195 ;       FN = FUNCTION = (PRADD)
                   196 ;     DATA = POSITION = (PRADD+1,+2)
                   197 ;       DB = DEADBAND = (PRADD+3)
                   198
00EC F5            199 DPROGM: PUSH    PSW
00ED C5            200         PUSH    B
00EE D5            201         PUSH    D
00EF E5            202         PUSH    H
                   203 ;GET PRADD, CONVERT TO ASCII,
                   204 ;AND STORE IN OPINFO+1,+2.
00F0 2A0000    E   205         LHLD    PRADD
00F3 7D            206         MOV     A,L
00F4 CDDB00    D   207         CALL    HXASC1
00F7 320100    E   208         STA     OPINFO+1
00FA 7D            209         MOV     A,L
00FB CDDF00    D   210         CALL    HEXASC          ;OPINFO+1,+2 CON
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

                              TAINS
 00FE 320200   E   211         STA     OPINFO+2        ;PROGRAM ADDRESS
                   212 ;GET FUNCTION,CONVERT TO ASCII,
                   213 ;AND STORE IN OPINFO+4,+5.
 0101 7E           214         MOV     A,M
 0102 FEF0         215         CPI     0F0H
 0104 D23C01   D   216         JNC     STOP
 0107 CDC101   D   217         CALL    FNASC   ;CONVERT FUNCTION TO ASC
                              II
                   218 ;FNASC WILL STORE ASCII DATA IN OPINFO+4,+5
                   219
                   220 ;RESET "STOP FUNCTION" FLAG
 010A 3E00         221         MVI     A,0
 010C 320000   E   222         STA     STOPFG
                   223
                   224 ;GET DATA, CONVERT TO ASCII, AND
                   225 ;STORE IN OPINFO+7,+8,+9,+10.
 010F 23           226         INX     H
 0110 56           227         MOV     D,M
 0111 23           228         INX     H
 0112 5E           229         MOV     E,M
 0113 EB           230         XCHG            ;HL = DATA
 0114 CD0000   E   231         CALL    SAVE
                   232 ;DATA STORED IN OPINFO+7 TO OPINFO+10
 0117 EB           233         XCHG            ;HL = (PRADD)+2
                   234 ;GET DEADBAND, CONVERT TO ASCII,
                   235 ;AND STORE IN OPINFO+12,+13.
 0118 23           236         INX     H
 0119 7E           237         MOV     A,M
 011A CDDB00   D   238         CALL    HXASC1
 011D 320C00   E   239         STA     OPINFO+12
 0120 7E           240         MOV     A,M
 0121 CDDF00   D   241         CALL    HEXASC          ;OPINFO+12,+13 C
                              ONTAINS
 0124 320D00   E   242         STA     OPINFO+13       ;DEADBAND DATA
                   243 ;OUTPUT 'PRGM*AD=XX FN-DATA-DB',
 0127 210E00   D   244         LXI     H,ODATA3
 012A 0E09         245         MVI     C,LDATA3
 012C CDCF00   D   246         CALL    OUTPUT  ;' PRGM*AD='
 012F 210100   E   247         LXI     H,OPINFO+1
 0132 0E0D         248         MVI     C,13
 0134 CDCF00   D   249         CALL    OUTPUT  ;( PRGM*AD=)XX FF-XXXX-X
                              X
 0137 E1           250 DP1:    POP     H
 0138 D1           251         POP     D
 0139 C1           252         POP     B
 013A F1           253         POP     PSW
 013B C9           254         RET
                   255
                   256 ;++++++++++++++++++++++++++++++++++++++++++++++++
                   257 ;DISPLAY PROGRAM STEP, FUNCTION="STOP"
 013C 3EFF         258 STOP:   MVI     A,0FFH
 013E 320000   E   259         STA     STOPFG
 0141 210E00   D   260         LXI     H,ODATA3
 0144 0E09         261         MVI     C,LDATA3
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0146 CDCF00   D    262          CALL    OUTPUT
0149 3A0100   E    263          LDA     OPINFO+1
014C CDBF00   D    264          CALL    XMIT
014F 3A0200   E    265          LDA     OPINFO+2
0152 CDBF00   D    266          CALL    XMIT
0155 212F00   D    267          LXI     H,ODATA7
0158 0E06          268          MVI     C,LDATA7
015A CDCF00   D    269          CALL    OUTPUT  ;' STOP '
015D C33701   D    270          JMP     DP1
                   271
                   272 ;*********************************************
                   273
                   274 ;DRSULT CALCULATES THE ABSOLUTE VALUE OF
                   275 ;THE ERROR (DESIRED POSITION - FINAL POSITION),
                   276 ;AND DISPLAYS BOTH THE FINAL POSITION
                   277 ;AND THE ERROR.
                   278
0160 F5            279 DRSULT: PUSH    PSW
0161 C5            280         PUSH    B
0162 E5            281         PUSH    H
                   282
                   283 ;DISPLAY CUTOFF POSITION:
0163 2A0000   E    284         LHLD    CUTOFF
0166 CD0000   E    285         CALL    SAVE
0169 211700   D    286         LXI     H,ODATA4
016C 0E07          287         MVI     C,LDATA4
016E CDCF00   D    288         CALL    OUTPUT  ;' CTOFF='
0171 210700   E    289         LXI     H,OPINFO+7
0174 0E04          290         MVI     C,4
0176 CDCF00   D    291         CALL    OUTPUT
                   292
                   293 ;DISPLAY FINAL POSITION:
0179 2A0000   E    294         LHLD    FINAL
017C CD0000   E    295         CALL    SAVE
                   296 ;SAVE CONVERTS FINAL POSITION TO ASCII AND
                   297 ;SAVES IN OPINFO+7 TO OPINFO+10
017F 210000   D    298         LXI     H,ODATA1
0182 0E07          299         MVI     C,LDATA1
0184 CDCF00   D    300         CALL    OUTPUT  ;' FINAL='
0187 210700   E    301         LXI     H,OPINFO+7
018A 0E04          302         MVI     C,4
018C CDCF00   D    303         CALL    OUTPUT  ;(FINAL=)'XXXX'
                   304
                   305 ;CALCULATE DIFFERENCE:
018F 2A0000   E    306         LHLD    PRADD
0192 23            307         INX     H
0193 46            308         MOV     B,M
0194 23            309         INX     H
0195 4E            310         MOV     C,M
                   311 ;GET A/D DATA:
0196 2A0000   E    312         LHLD    FINAL   ;HL = A/D DATA
                   313 ;SUBTRACT:
0199 79            314         MOV     A,C
019A 95            315         SUB     L
019B 6F            316         MOV     L,A
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

019C 78            317         MOV     A,B
019D 9C            318         SBB     H
019E 67            319         MOV     H,A
                   320 ;DIFFERENCE IS IN REG HL,
                   321 ;CALCULATE ABSOLUTE VALUE.
019F D2AA01    D   322         JNC     D1      ;IF NO BORROW, THEN OK
01A2 3E00          323         MVI     A,0
01A4 95            324         SUB     L
01A5 6F            325         MOV     L,A
01A6 3E00          326         MVI     A,0
01A8 9C            327         SBB     H
01A9 67            328         MOV     H,A
                   329
                   330 ;OUTPUT DIFFERENCE DATA:
01AA CD0000    E   331 D1:     CALL    SAVE
01AD 210700    D   332         LXI     H,ODATA2
01B0 0E07          333         MVI     C,LDATA2
01B2 CDCF00    D   334         CALL    OUTPUT  ;' DIFF=='
01B5 210700    E   335         LXI     H,OPINFO+7
01B8 0E04          336         MVI     C,4
01BA CDCF00    D   337         CALL    OUTPUT  ;(DIFF==)' XXXX'
01BD E1            338         POP     H
01BE C1            339         POP     B
01BF F1            340         POP     PSW
01C0 C9            341         RET
                   342
                   343 ;*********************************************
                   344
                   345 ;FNASC CONVERTS FUNCTION(PASSED IN ACC) TO ASCII
                   346 ;ASCII DATA IS STORED IN OPINFO+4,+5 BY FNASC
                   347
01C1 F5            348 FNASC:  PUSH    PSW
01C2 C5            349         PUSH    B
01C3 E60F          350         ANI     0FH
01C5 CAF701    D   351         JZ      SU      ;SU = 0
01C8 3D            352         DCR     A
01C9 CAFD01    D   353         JZ      SL
01CC 3D            354         DCR     A
01CD CA0302    D   355         JZ      EU
01D0 3D            356         DCR     A
01D1 CA0902    D   357         JZ      EE
01D4 3D            358         DCR     A
01D5 CA0F02    D   359         JZ      WU
01D8 3D            360         DCR     A
01D9 CA1502    D   361         JZ      WL      ;WL = 5
01DC 3D            362         DCR     A
01DD CA1B02    D   363         JZ      WR
01E0 3D            364         DCR     A
01E1 3D            365         DCR     A
01E2 CA2102    D   366         JZ      HO      ;HO = 8
01E5 3D            367         DCR     A
01E6 CA2702    D   368         JZ      HC      ;HC = 9
01E9 013F3F        369         LXI     B,'??'
01EC 78            370 RET1:   MOV     A,B
01ED 320400    E   371         STA     OPINFO+4
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 01F0 79            372         MOV     A,C
 01F1 320500   E    373         STA     OPINFO+5
 01F4 C1            374         POP     B
 01F5 F1            375         POP     PSW
 01F6 C9            376         RET
 01F7 015553        377 SU:     LXI     B,'SU'
 01FA C3EC01   D    378         JMP     RET1
 01FD 014C53        379 SL:     LXI     B,'SL'
 0200 C3EC01   D    380         JMP     RET1
 0203 015545        381 EU:     LXI     B,'EU'
 0206 C3EC01   D    382         JMP     RET1
 0209 014545        383 EE:     LXI     B,'EE'
 020C C3EC01   D    384         JMP     RET1
 020F 015557        385 WU:     LXI     B,'WU'
 0212 C3EC01   D    386         JMP     RET1
 0215 014C57        387 WL:     LXI     B,'WL'
 0218 C3EC01   D    388         JMP     RET1
 021B 015257        389 WR:     LXI     B,'WR'
 021E C3EC01   D    390         JMP     RET1
 0221 014F48        391 HO:     LXI     B,'HO'
 0224 C3EC01   D    392         JMP     RET1
 0227 014348        393 HC:     LXI     B,'HC'
 022A C3EC01   D    394         JMP     RET1
                    395
                    396         END


PUBLIC SYMBOLS
DISP   D 0035    DPROGM D 00EC    DRSULT D 0160    FNASC  D 01C1
HEXASC D 00DF    HXASC1 D 00DB    OUTPUT D 00CF    XMIT   D 00BF

EXTERNAL SYMBOLS
ASCHEX E 0000    ASCHX1 E 0000    CUTOFF E 0000    ERROR  E 0000
EXIT   E 0000    FINAL  E 0000    OPINFO E 0000    PRADD  E 0000
PROMT  E 0000    SAVE   E 0000    START1 E 0000    STOPFG E 0000
USRT   E 0000    WAIT   E 0000

USER SYMBOLS
ASCHEX E 0000    ASCHX1 E 0000    CUTOFF E 0000    D1     D 01AA
D4     D 009A    DISP   D 0035    DISP1  D 0048    DISP2  D 005C
DISP2A D 0065    DISP3  D 007E    DISP4  D 0097    DP1    D 0137
DPROGM D 00EC    DRSULT D 0160    EE     D 0209    ERROR  E 0000
EU     D 0203    EXIT   E 0000    FINAL  E 0000    FNASC  D 01C1
HC     D 0227    HEX1   D 00E9    HEXASC D 00DF    HO     D 0221
HXASC1 D 00DB    LDATA1 A 0007    LDATA2 A 0007    LDATA3 A 0009
LDATA4 A 0007    LDATA5 A 0009    LDATA6 A 0008    LDATA7 A 0006
ODATA1 D 0000    ODATA2 D 0007    ODATA3 D 000E    ODATA4 D 0017
ODATA5 D 001E    ODATA6 D 0027    ODATA7 D 002F    OPINFO E 0000
OUTPUT D 00CF    PRADD  E 0000    PROMT  E 0000    RET1   D 01EC
SAVE   E 0000    SL     D 01FD    START1 E 0000    STOP   D 013C
STOPFG E 0000    SU     D 01F7    USRT   E 0000    WAIT   E 0000
WL     D 0215    WR     D 021B    WU     D 020F    XMIT   D 00BF
XMIT1  D 00C1

ASSEMBLY COMPLETE,  NO ERRORS
```

```
ASCHEX    13     71     93    109
ASCHX1    13     58
CUTOFF    15    284
D1       322    331#
D4        88    110#
DISP      11     44#
DISP1     50     55#
DISP2     56     65#
DISP2A    66     71#
DISP3     60     92#
DISP4    101    109#   125
DP1      250#   270
DPROGM    12    111    199#
DRSULT    12    279#
EE       357    383#
ERROR     15
EU       355    381#
EXIT      13     51     61     67    102
FINAL     14    294    312
FNASC     12    217    348#
HC       368    393#
HEX1     176    179#
HEXASC    11    174#   210    241
HO       366    391#
HXASC1    11    170#   207    238
LDATA1    30#   299
LDATA2    31#   333
LDATA3    32#   245    261
LDATA4    33#   287
LDATA5    34#    45
LDATA6    35#    99
LDATA7    36#   268
ODATA1    22#   298
ODATA2    23#   332
ODATA3    24#   244    260
ODATA4    25#   286
ODATA5    26#    44
ODATA6    27#    98
ODATA7    28#   267
OPINFO    14     57     92    208    211    239    242    247    263
         265    289    301    335    371    373
OUTPUT     1     12     46    100    154#   159    246    249    262
         269    288    291    300    303    334    337
PRADD     14     49     59     83     94    116    119    205    306
PROMT     16     75
RET1     370#   378    380    382    384    386    388    390    392
         394
SAVE      15    231    285    295    331
SL       353    379#
START1    15    122    126
STOP     216    258#
STOPFG    16    120    222    259
SU       351    377#
USRT      14    135    139
WAIT      13    114
WL       361    387#
WR       363    389#
```

```
NU       359    385#
XMIT      11     65    133#   156    264    266
XMIT1    135#   137
```

CROSS REFERENCE COMPLETE

```
ASM80 :F1:PROGW.ASY XREF PAGEWIDTH(72)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         PROGW    PAGE    1

  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    PROGW

                          ;PROGRAMMER:  C.MORRIN
                       4  ;VERSION 2.0W
                       5  ;DATE OF LAST CHANGE:  NOVEMBER 3, 1977
                       6
                       7  ;*********************************************
                       8
                       9          CSEG
                      10
                      11          PUBLIC  PROGR,PRG11B
                      12  ;PROGXX ADDRESSES ARE ALSO ENTRY POINTS
                      13          EXTRN   PRADD,OUTPUT,WAIT
                      14          EXTRN   TRANSO
                      15          EXTRN   STATE,EXIT,ERROR,OPINFO
                      16          EXTRN   START1,DPROGM,GETPOT,XMIT
                      17          EXTRN   ASCHEX,ASCHX1,HEXASC,HXASC1
                      18
                      19  ;*********************************************
                      20
                      21  ;OUTPUT MESSAGE TABLE:
                      22          DSEG
                      23
0000 20505247         24  OPRG1:  DB      ' PRGM*AD='
0004 4D2A4144
0008 3D
0009 20532C45         25  OPRG2:  DB      ' S,E,W,H, T, OR N?'
000D 2C572C48
0011 2C20542C
0015 204F5220
0019 4E3F
001B 20444541         26  OPRG3:  DB      ' DEADBND='
001F 44424E44
0023 3D
0024 20444154         27  OPRG4:  DB      ' DATA='
0028 413D
002A 204F5045         28  OPRG5:  DB      ' OPEN OR CLOSE?'
002E 4E204F52
0032 20434C4F
0036 53453F
0039 2055204F         29  OPRG6:  DB      ' U OR L?'
003D 52204C3F
0041 20454E44         30  OPRG7:  DB      ' END OF PROGRAM'
0045 204F4620
0049 50524F47
004D 52414D
0050 2055204F         31  OPRG8:  DB      ' U OR E?'
0054 5220453F
                      32
0009                  33  LPRG1   EQU     9
0012                  34  LPRG2   EQU     18
0009                  35  LPRG3   EQU     9
0006                  36  LPRG4   EQU     6
000F                  37  LPRG5   EQU     15
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

 0008               38 LPRG6   EQU     8
 000F               39 LPRG7   EQU     15
 0008               40 LPRG8   EQU     8
                    41
                    42 ;************************************************
                    43
                    44 ;PROGRAM ROUTINE:
                    45
                    46 ;THIS ROUTINE PROVIDES THE BULK OF THE HAND
                    47 ;CONTROLLER INTERFACE REQUIRED TO PROGRAM
                    48 ;THE PROGRAMMER.THE PROGRAMMER
                    49 ;ACCEPTS AND OPERATES ON ONE CHARACTER AT A
                    50 ;TIME.  A FINITE STATE STRUCTURE IS USED TO
                    51 ;DETERMINE THE INTERPRETION OF THE
                    52 ;INCOMING DATA.
                    53
                    54          CSEG
                    55
                    56 ;++++++++++++++++++++++++++++++++++++++++++++++++
                    57 ;PROGRAM MODE, REQUEST ADDRESS INFORMATION
 0000 210000    D   58 PROGR:  LXI     H,OPRG1 ;'PROGRAM ADDRESS='
 0003 0E09          59         MVI     C,LPRG1
 0005 CD0000    E   60         CALL    OUTPUT
 0008 210E00    C   61         LXI     H,PROG2
 000B C30000    E   62         JMP     EXIT
                    63
                    64
                    65 ;++++++++++++++++++++++++++++++++++++++++++++++++
                    66 ;PROGRAM MODE, FIRST ADDRESS DIGIT
 000E 320100    E   67 PROG2:  STA     OPINFO+1  ;ADDRESS BYTE, HIGH
 0011 CD0000    E   68         CALL    ASCHX1
 0014 320000    E   69         STA     PRADD
 0017 211D00    C   70         LXI     H,PROG3   ;CALL PROG3 NEXT
 001A C30000    E   71         JMP     EXIT
                    72
                    73 ;++++++++++++++++++++++++++++++++++++++++++++++++
                    74 ;PROGRAM MODE, SECOND ADDRESS DIGIT.
                    75 ;REQUEST FUNCTION CHARACTER
 001D 320200    E   76 PROG3:  STA     OPINFO+2  ;ADDRESS BYTE, LOW
 0020 CD0000    E   77         CALL    ASCHEX
 0023 210000    E   78         LXI     H,PRADD
 0026 B6            79         ORA     M
 0027 77            80         MOV     M,A
                    81 ;STORE 2 HEX DIGITS IN PRADD
 0028 01204E        82         LXI     B,20000D
                    83 ;WAIT 1 SECOND = 2000 X 50 MICROSECONDS
 002B CD0000    E   84         CALL    WAIT
                    85
                    86 ;++++++++++++++++++++++++++++++++++++++++++++++++
                    87 ; THIS IS THE STARTING POINT AFTER A STEP HAS
                    88 ;ALREADY BEEN PROGRAMMED.
 002E 210900    D   89 PROG3Y: LXI     H,OPRG2
 0031 0E12          90         MVI     C,LPRG2 .
 0033 CD0000    E   91         CALL    OUTPUT  ;' SU,SL,E,W, T, OR N?'
 0036 213C00    C   92         LXI     H,PROG4 ;CALL PROG4 NEXT
```

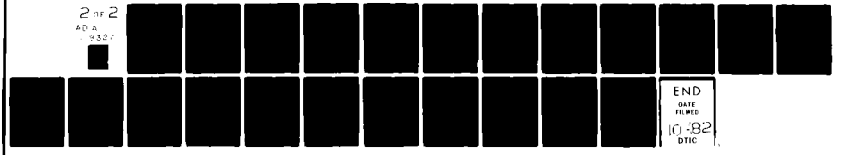
```
LOC  OBJ          LINE        SOURCE STATEMENT

0039 C30000   E    93          JMP     EXIT
                   94
                   95 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   96 ;PROGRAM MODE, INPUT FIRST FUNCTION CHARACTER.
                   97 ;SHOULDER GROUP, ELBOW GROUP, OR WRIST GROUP?
                   98 ;(EXTEND IS PART OF ELBOW GROUP).
003C FE4E          99 PROG4:  CPI     'N'
003E CAA700   C   100          JZ      PROG4N
0041 FE54         101          CPI     'T'
0043 CA0000   E   102          JZ      TRANS0
0046 320400   E   103          STA     OPINFO+4
0049 FE48         104          CPI     'H'
004B CA6000   C   105          JZ      PROG4H
004E FE53         106          CPI     'S'
0050 CA7000   C   107          JZ      PROG4S
0053 FE45         108          CPI     'E'
0055 CA8000   C   109          JZ      PROG4E
0058 FE57         110          CPI     'W'
005A CA9000   C   111          JZ      PROG4W
005D C30000   E   112          JMP     ERROR
                  113
                  114 ;HAND OPEN  = 1000 BINARY
                  115 ;HAND CLOSE = 1001 BINARY
0060 CD0000   E   116 PROG4H: CALL    XMIT
0063 212A00   D   117          LXI     H,OPRG5
0066 0E0F         118          MVI     C,LPRG5
0068 CD0000   E   119          CALL    OUTPUT  ;'OPEN OR CLOSE?'
006B 3E08         120          MVI     A,8
006D C39D00   C   121          JMP     END4
                  122
0070 CD0000   E   123 PROG4S: CALL    XMIT
0073 213900   D   124          LXI     H,OPRG6
0076 0E08         125          MVI     C,LPRG6
0078 CD0000   E   126          CALL    OUTPUT
007B 3E00         127          MVI     A,0
                  128 ;SHOULDER UP/DN = 000 BINARY
                  129 ;SHOULDER LF/RT = 001 BINARY
007D C39D00   C   130          JMP     END4
                  131
0080 CD0000   E   132 PROG4E: CALL    XMIT
                  133 ;ELBOW UP/DN  = 010 BINARY
                  134 ;ELBOW EXTEND = 011 BINARY
0083 215000   D   135          LXI     H,OPRG8
0086 0E08         136          MVI     C,LPRG8
0088 CD0000   E   137          CALL    OUTPUT  ;'UP/DOWN=U EXTEND=E
008B 3E02         138          MVI     A,2
008D C39D00   C   139          JMP     END4
                  140
0090 CD0000   E   141 PROG4W: CALL    XMIT
                  142 ;WRIST UP/DN  = 100 BINARY
                  143 ;WRIST LF/RT  = 101 BINARY
0093 213900   D   144          LXI     H,OPRG6
0096 0E08         145          MVI     C,LPRG6
0098 CD0000   E   146          CALL    OUTPUT  ;' UP/DOWN=U LEFT/RT=L'
009B 3E04         147          MVI     A,4
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

009D 2A0000   E    148 END4:   LHLD    PRADD
00A0 77            149         MOV     M,A
00A1 21BD00   C    150         LXI     H,PROG5
00A4 C30000   E    151         JMP     EXIT
                   152
                   153 ;END OF PROGRAM MODE. INSERT STOP
                   154 ;FLAG AT END OF PROGRAM.
00A7 214100   D    155 PROG4N: LXI     H,OPRG7
00AA 0E0F          156         MVI     C,LPRG7
00AC CD0000   E    157         CALL    OUTPUT
00AF 011027        158         LXI     B,10000
00B2 CD0000   E    159         CALL    WAIT    ;WAIT .5 SEC
00B5 2A0000   E    160         LHLD    PRADD
00B8 36FF          161         MVI     M,0FFH
                   162 ;SET STOP FLAG IN PROGRAM
00BA C30000   E    163         JMP     START1
                   164
                   165 ;++++++++++++++++++++++++++++++++++++++++++++++++
                   166 ;PROGRAM MODE, SECOND FUNCTION CHARACTER
00BD 320500   E    167 PROG5:  STA     OPINFO+5
00C0 FE55          168         CPI     'U'
00C2 CAE000   C    169         JZ      UP
00C5 2A0000   E    170         LHLD    PRADD
00C8 FE45          171         CPI     'E'
00CA CAFE00   C    172         JZ      EXTEND
00CD FE4C          173         CPI     'L'
00CF CADF00   C    174         JZ      LEFT
00D2 FE4F          175         CPI     'O'
00D4 CA0601   C    176         JZ      OPEN
00D7 FE43          177         CPI     'C'
00D9 CA0501   C    178         JZ      CLOSE
00DC C30000   E    179         JMP     ERROR
                   180
00DF 34            181 LEFT:   INR     M
00E0 210000   D    182 UP:     LXI     H,OPRG1
00E3 0E09          183         MVI     C,LPRG1
00E5 CD0000   E    184         CALL    OUTPUT  ;' PROG#AD='
00E8 210100   E    185         LXI     H,OPINFO+1
00EB 0E05          186         MVI     C,5
00ED CD0000   E    187         CALL    OUTPUT  ;OUTPUT  'AA FF'
00F0 212400   D    188         LXI     H,OPRG4
00F3 0E06          189         MVI     C,LPRG4
00F5 CD0000   E    190         CALL    OUTPUT  ;' DATA='
                   191 ;DISPLAY NOW READS  'PROG#AD=AA'
                   192 ;                   'FF DATA='
00F8 212601   C    193         LXI     H,PROG6
00FB C30000   E    194         JMP     EXIT
                   195
00FE 7E            196 EXTEND: MOV     A,M     ;CORRECT FUNCT
00FF F603          197         ORI     3
0101 77            198         MOV     M,A
0102 C3E000   C    199         JMP     UP
                   200 ;OUTPUT 'AA FF', UPDATE STATE AND EXIT
                   201
0105 34            202 CLOSE:  INR     M
```

AD-A119 327 NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA F/G 13/10
WORK SYSTEMS PACKAGE AUTOMATIC TOOL INTERCHANGE. LABORATORY STU--ETC(U)
JUN 82 C E MORRIN .
UNCLASSIFIED NOSC/TR-262 NL



```
 LOC  OBJ          LINE        SOURCE STATEMENT

 0106 23            203 OPEN:   INX     H
 0107 3600          204         MVI     M,0
 0109 23            205         INX     H
 010A 3600          206         MVI     M,0
 010C 23            207         INX     H
 010D 3600          208         MVI     M,0
 010F 3E30          209         MVI     A,'0'
 0111 320700    E   210         STA     OPINFO+7
 0114 320800    E   211         STA     OPINFO+8
 0117 320900    E   212         STA     OPINFO+9
 011A 320A00    E   213         STA     OPINFO+10
 011D 320C00    E   214         STA     OPINFO+12
 0120 320D00    E   215         STA     OPINFO+13
 0123 C3EB01    C   216         JMP     PRG11A
                    217 ;NOTE: REG HL=(PRADD)+3 AS REQUIRED
                    218
                    219 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    220 ;PROGRAM MODE, FIRST DATA DIGIT
 0126 FE2A          221 PROG6:  CPI     '*'
 0128 CA4E01    C   222         JZ      PROG6A  ;AUTO DATA READ
 012B 320700    E   223         STA     OPINFO+7 ;FIRST DATA BYTE, HIGH
 012E CD0000    E   224         CALL    ASCHX1
 0131 2A0000    E   225         LHLD    PRADD
 0134 23            226         INX     H
                    227 ;REG HL HAS PROGRAM ADDRESS FOR FIRST DATA BYTE
 0135 77            228         MOV     M,A
                    229 ;STORE FIRST HALF OF FIRST DATA BYTE
 0136 213C01    C   230         LXI     H,PROG7 ;CALL PROG7 NEXT
 0139 C30000    E   231         JMP     EXIT
                    232
                    233 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    234 ;PROGRAM MODE, SECOND DATA DIGIT
 013C 320800    E   235 PROG7:  STA     OPINFO+8 ;FIRST DATA BYTE, LOW
 013F CD0000    E   236         CALL    ASCHEX
 0142 2A0000    E   237         LHLD    PRADD
 0145 23            238         INX     H
                    239 ;H = PROGRAM ADDRESS OF FIRST BYTE
 0146 B6            240         ORA     M     ;COMBINE BOTH DATA HALVES
 0147 77            241         MOV     M,A   ;STORE FIRST DATA BYTE
 0148 218501    C   242         LXI     H,PROG8
 014B C30000    E   243         JMP     EXIT
                    244
                    245 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    246 ;AUTOMATIC DATA READ
 014E CD0000    E   247 PROG6A: CALL    GETPOT
                    248 ;DATA WILL BE STORED IN PRADD+1,+2,OPINFO+8-11
                    249 ;NEED TO SET APPROPRIATE DEADBAND:
 0151 2A0000    E   250         LHLD    PRADD
 0154 7E            251         MOV     A,M     ;GET FUNCTION
 0155 FE00          252         CPI     0
 0157 CA7601    C   253         JZ      XSU
 015A FE01          254         CPI     1
 015C CA7B01    C   255         JZ      XSL
 015F FE02          256         CPI     2
 0161 CA7B01    C   257         JZ      XSL     ;EU
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

0164 FE03          258         CPI     3
0166 CA7601   C    259         JZ      XSU     ;EE
0169 FE04          260         CPI     4
016B CA7601   C    261         JZ      XSU     ;WU
016E FE05          262         CPI     5
0170 CA7B01   C    263         JZ      XSL     ;WL
0173 C30000   E    264         JMP     START1
0176 3E03          265 XSU:    MVI     A,3
0178 C37D01   C    266         JMP     XX
017B 3E05          267 XSL:    MVI     A,5
017D 110300        268 XX:     LXI     D,3
0180 19            269         DAD     D       ;HL = (PRADD)+3
0181 77            270         MOV     M,A     ;STORE DEADBAND
0182 C3EB01   C    271         JMP     PRG11A
                   272
                   273 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   274 ;PROGRAM MODE, THIRD DATA DIGIT
0185 320900   E    275 PROG8:  STA     OPINFO+9 ;SECOND DATA BYTE, HIGH
0188 CD0000   E    276         CALL    ASCHX1
018B 2A0000   E    277         LHLD    PRADD
018E 23            278         INX     H
018F 23            279         INX     H
0190 77            280         MOV     M,A
0191 219701   C    281         LXI     H,PROG9
0194 C30000   E    282         JMP     EXIT
                   283
                   284 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   285 ;PROGRAM MODE, FOURTH DATA DIGIT
0197 320A00   E    286 PROG9:  STA     OPINFO+10 ;SECOND DATA BYTE, LOW
019A CD0000   E    287         CALL    ASCHEX
019D 2A0000   E    288         LHLD    PRADD
01A0 23            289         INX     H
01A1 23            290         INX     H
01A2 B6            291         ORA     M
01A3 77            292         MOV     M,A
                   293 ;STORE SECOND DATA BYTE IN PROGRAM
01A4 210000   D    294         LXI     H,OPRG1
01A7 0E09          295         MVI     C,LPRG1
01A9 CD0000   E    296         CALL    OUTPUT  ;' PROG*AD='
01AC 210100   E    297         LXI     H,OPINFO+1
01AF 0E0A          298         MVI     C,10
01B1 CD0000   E    299         CALL    OUTPUT  ;'AA FF-DDDD'
                   300 ;DISPLAY NOW READS  'PROG*AD=AA'
                   301 ;                   'FF-DDDD'
01B4 011027        302         LXI     B,10000
01B7 CD0000   E    303         CALL    WAIT    ;WAIT .5 SECOND
01BA 211B00   D    304         LXI     H,OPRG3
01BD 0E09          305         MVI     C,LPRG3
01BF CD0000   E    306         CALL    OUTPUT  ;'DEADBAND='
01C2 21CB01   C    307         LXI     H,PROG10
01C5 C30000   E    308         JMP     EXIT
                   309
                   310 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   311 ;PROGRAM MODE, FIRST DEADBAND DIGIT
01C8 320C00   E    312 PROG10: STA     OPINFO+12 ;DEADBAND BYTE, HIGH
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

01CB CD0000   E    313          CALL     ASCHX1
01CE 2A0000   E    314          LHLD     PRADD
01D1 110300        315          LXI      D,3
01D4 19            316          DAD      D        ;HL = (PRADD)+3
01D5 77            317          MOV      M,A
                   318 ;STORE FIRST HALF OF DEADBAND DATA IN PRADD
01D6 21DC01   C    319          LXI      H,PROG11
01D9 C30000   E    320          JMP      EXIT
                   321
                   322 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   323 ;PROGRAM MODE, SECOND DEADBAND DIGIT
01DC 320D00   E    324 PROG11: STA      OPINFO+13 ;DEADBAND BYTE, LOW
01DF CD0000   E    325          CALL     ASCHEX
01E2 2A0000   E    326          LHLD     PRADD
01E5 110300        327          LXI      D,3
01E8 19            328          DAD      D        ;HL = (PRADD)+3
01E9 B6            329          ORA      M
01EA 77            330          MOV      M,A
                   331
                   332 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   333 ;DISPLAY COMPLETED PROGRAM STEP AND GET
                   334 ;READY TO PROGRAM ANOTHER.
                   335 ;NOTE:  REG HL = (PRADD)+3 FOR ENTRY HERE
01EB CD0000   E    336 PRG11A: CALL     DPROGM
                   337 ;DISPLAY IS NOW:  'PROG*AD=AA'
                   338 ;                 'FF-DDDD-DB'
                   339 ;UPDATE PRADD:
01EE 23            340          INX      H        ;HL=(PRADD)+4
01EF 220000   E    341          SHLD     PRADD
                   342
                   343 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                   344 ;EXTERNAL ENTRY POINT (RETURN FROM TRANSFER)
                   345 ;GET READY TO PROGRAM ANOTHER STEP:
01F2 3A0000   E    346 PRG11B: LDA      PRADD
01F5 CD0000   E    347          CALL     HXASC1
01F8 320100   E    348          STA      OPINFO+1
                   349 ;STORE FIRST DIGIT OF ADDRESS
01FB 3A0000   E    350          LDA      PRADD
01FE CD0000   E    351          CALL     HEXASC
0201 320200   E    352          STA      OPINFO+2
                   353 ;STORE 2ND DIGIT OF ADDRESS
0204 210000   D    354          LXI      H,OPRG1
0207 0E09          355          MVI      C,LPRG1
0209 CD0000   E    356          CALL     OUTPUT   ;'PROGRAM ADDRESS='
020C 210100   E    357          LXI      H,OPINFO+1
020F 0E02          358          MVI      C,2
0211 CD0000   E    359          CALL     OUTPUT   ;'AA'
0214 011027        360          LXI      B,10000 ;WAIT .5 SECOND
0217 CD0000   E    361          CALL     WAIT
021A C32E00   C    362          JMP      PROG3Y
                   363
                   364 ;*************************************************
                   365
                   366          END
```

```
PUBLIC SYMBOLS
PRG11B C 01F2    PROGR  C 0000

EXTERNAL SYMBOLS
ASCHEX E 0000    ASCHX1 E 0000    DPROGM E 0000    ERROR  E 0000
EXIT   E 0000    GETPOT E 0000    HEXASC E 0000    HXASC1 E 0000
OPINFO E 0000    OUTPUT E 0000    PRADD  E 0000    START1 E 0000
STATE  E 0000    TRANSO E 0000    WAIT   E 0000    XMIT   E 0000

USER SYMBOLS
ASCHEX E 0000    ASCHX1 E 0000    CLOSE  C 0105    DPROGM E 0000
END4   C 009D    ERROR  E 0000    EXIT   E 0000    EXTEND C 00FE
GETPOT E 0000    HEXASC E 0000    HXASC1 E 0000    LEFT   C 00DF
LPRG1  A 0009    LPRG2  A 0012    LPRG3  A 0009    LPRG4  A 0006
LPRG5  A 000F    LPRG6  A 0008    LPRG7  A 000F    LPRG8  A 0008
OPEN   C 0106    OPINFO E 0000    OPRG1  D 0000    OPRG2  D 0009
OPRG3  D 001B    OPRG4  D 0024    OPRG5  D 002A    OPRG6  D 0039
OPRG7  D 0041    OPRG8  D 0050    OUTPUT E 0000    PRADD  E 0000
PRG11A C 01EB    PRG11B C 01F2    PROG10 C 01C8    PROG11 C 01DC
PROG2  C 000E    PROG3  C 001D    PROG3Y C 002E    PROG4  C 003C
PROG4E C 0080    PROG4H C 0060    PROG4N C 00A7    PROG4S C 0070
PROG4W C 0090    PROG5  C 00BD    PROG6  C 0126    PROG6A C 014E
PROG7  C 013C    PROG8  C 0185    PROG9  C 0197    PROGR  C 0000
START1 E 0000    STATE  E 0000    TRANSO E 0000    UP     C 00E0
WAIT   E 0000    XMIT   E 0000    XSL    C 017B    XSU    C 0176
XX     C 017D

ASSEMBLY COMPLETE,  NO ERRORS
```

ISIS-II ASSEMBLER SYMBOL CROSS-REFERENCE, V2.1

ASCHEX	17	77	236	287	325				
ASCHX1	17	68	224	276	313				
CLOSE	178	202#							
DPROGM	16	336							
END4	121	130	139	148#					
ERROR	15	112	179						
EXIT	15	62	71	93	151	194	231	243	282
	308	320							
EXTEND	172	196#							
GETPOT	16	247							
HEXASC	17	351							
HXASC1	17	347							
LEFT	174	181#							
LPRG1	33#	59	183	295	355				
LPRG2	34#	90							
LPRG3	35#	305							
LPRG4	36#	189							
LPRG5	37#	118							
LPRG6	38#	125	145						
LPRG7	39#	156							
LPRG8	40#	136							
OPEN	176	203#							
OPINFO	15	67	76	103	167	185	210	211	212
	213	214	215	223	235	275	286	297	312
	324	348	352	357					
OPRG1	24#	58	182	294	354				
OPRG2	25#	89							
OPRG3	26#	304							
OPRG4	27#	188							
OPRG5	28#	117							
OPRG6	29#	124	144						
OPRG7	30#	155							
OPRG8	31#	135							
OUTPUT	13	60	91	119	126	137	146	157	184
	187	190	296	299	306	356	359		
PRADD	13	69	78	148	160	170	225	237	250
	277	288	314	326	341	346	350		
PRG11A	216	271	336#						
PRG11B	11	346#							
PROG10	307	312#							
PROG11	319	324#							
PROG2	61	67#							
PROG3	70	76#							
PROG3Y	89#	362							
PROG4	92	99#							
PROG4E	109	132#							
PROG4H	105	116#							
PROG4N	100	155#							
PROG4S	107	123#							
PROG4W	111	141#							
PROG5	150	167#							
PROG6	193	221#							
PROG6A	222	247#							
PROG7	230	235#							
PROG8	242	275#							
PROG9	281	286#							
PROGR	11	58#							

```
PROGW      1
START1    16     163     264
STATE     15
TRANSO    14     102
UP       169     182#    199
WAIT      13      84     159     303     361
XMIT      16     116     123     132     141
XSL      255     257     263     267#
XSU      253     259     261     265#
XX       266     268#

CROSS REFERENCE COMPLETE
```

```
ASM80 :F1:RDPOTW.ASY XREF PAGEWIDTH(72) PRINT(:LP:)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         RDPOTW   PAGE    1

  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    RDPOTW
                       2
                       3 ;PROGRAMMER:  C. MORRIN
                       4 ;VERSION 1.0W
                       5 ;DATE OF LAST CHANGE:  OCTOBER 25, 1977
                       6
                       7 ;*************************************************
                       8
                       9          CSEG
                      10
                      11          PUBLIC  RDPOT
                      12          EXTRN   START1,ERROR,EXIT,POTFLG
                      13          EXTRN   DISPOT,OUTPUT
                      14
                      15 ;*************************************************
                      16
                      17          DSEG
                      18
0000 20412C53         19 OT1:     DB      ' A,S,E OR W?'
0004 2C45204F
0008 5220573F
000C 20412C55         20 OT2:     DB      ' A,U OR L?'
0010 204F5220
0014 4C3F
                      21
000C                  22 LT1      EQU     12
000A                  23 LT2      EQU     10
                      24
                      25 ;*************************************************
                      26
                      27          CSEG
                      28
                      29 ;HAND CONTROLLER INTERFACE:
                      30
                      31 ;READ POTENTIOMETER MODE, WHICH ONE?
                      32 ;ALL, SHOULDER GROUP, ELBOW GROUP,
                      33 ; OR WRIST GROUP?
0000 210000    D      34 RDPOT:   LXI     H,OT1
0003 0E0C             35          MVI     C,LT1
0005 CD0000    E      36          CALL    OUTPUT      ;' SELECT: A/S/E/W'
0008 210E00    C      37          LXI     H,INPT40
0008 C30000    E      38          JMP     EXIT
                      39
                      40 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                      41 ;READ POTENTIOMETER MODE, GROUP?
000E FE41             42 INPT40:  CPI     'A'
0010 CA2500    C      43          JZ      RALL
0013 FE53             44          CPI     'S'
0015 CA4A00    C      45          JZ      RSHLDR
0018 FE45             46          CPI     'E'
001A CA5800    C      47          JZ      RELBOW
001D FE57             48          CPI     'W'
001F CA6600    C      49          JZ      RWRIST
0022 C30000    E      50          JMP     ERROR
```

```
 LOC  OBJ          LINE        SOURCE STATEMENT

                     51
                     52 ;"ALL" SELECTED, READ ALL POTS:
0025 212500    C     53 RALL:   LXI     H,RALL
0028 220000    E     54         SHLD    POTFLG
002B 3E00            55         MVI     A,0
002D CD0000    E     56         CALL    DISPOT  ;SU = 0
0030 3E01            57         MVI     A,1
0032 CD0000    E     58         CALL    DISPOT  ;SL = 1
0035 3E02            59         MVI     A,2
0037 CD0000    E     60         CALL    DISPOT  ;EU = 2
003A 3E04            61         MVI     A,4
003C CD0000    E     62         CALL    DISPOT  ;WU = 4
003F 3E05            63         MVI     A,5
0041 CD0000    E     64         CALL    DISPOT  ;WL = 5
                     65
                     66 ;THIS IS THE "END OF READ POT" RETURN.
0044 217400    C     67 END40:  LXI     H,INPT41
0047 C30000    E     68         JMP     EXIT
                     69
                     70 ;"SHOULDER" SELECTED, WHICH POT?
004A 210C00    D     71 RSHLDR: LXI     H,QT2
004D 0E0A            72         MVI     C,LT2
004F CD0000    E     73         CALL    OUTPUT  ;' SELECT: A/U/L'
0052 218500    C     74         LXI     H,INPT42
0055 C30000    E     75         JMP     EXIT
                     76
                     77 ;"ELBOW" SELECTED, READ ELBOW POT:
0058 215800    C     78 RELBOW: LXI     H,RELBOW
005B 220000    E     79         SHLD    POTFLG
005E 3E02            80         MVI     A,2
0060 CD0000    E     81         CALL    DISPOT  ;EU = 2
0063 C34400    C     82         JMP     END40
                     83
                     84 ;"WRIST" SELECTED, WHICH POT?
0066 210C00    D     85 RWRIST: LXI     H,QT2
0069 0E0A            86         MVI     C,LT2
006B CD0000    E     87         CALL    OUTPUT  ;' SELECT A/U/L'
006E 21C600    C     88         LXI     H,INPT43
0071 C30000    E     89         JMP     EXIT
                     90
                     91 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                     92 ;READ POTENTIOMETER MODE, UPDATE READING
                     93 ;OR GO BACK TO START? (U OR S?)
0074 FE55            94 INPT41: CPI     'U'
0076 CA8100    C     95         JZ      UPDATE
0079 FE53            96         CPI     'S'
007B CA0000    E     97         JZ      START1
007E C30000    E     98         JMP     ERROR
                     99
                    100 ;READ POT AGAIN, POTFLG IS ADDRESS OF
                    101 ;APPROPRIATE ROUTINE.
0081 2A0000    E    102 UPDATE: LHLD    POTFLG
0084 E9              103         PCHL
                    104
                    105 ;+++++++++++++++++++++++++++++++++++++++++++++++++
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

                   106 ;READ SHOULDER POTENTIOMETER, WHICH ONE?
0085 FE41          107 INPT42: CPI     'A'
0087 CA9700    C   108         JZ      RSA
008A FE55          109         CPI     'U'
008C CAAA00    C   110         JZ      RSU
008F FE4C          111         CPI     'L'
0091 CAB800    C   112         JZ      RSL
0094 C30000    E   113         JMP     ERROR
                   114
                   115 ;READ ALL SHOULDER POTS
0097 219700    C   116 RSA:    LXI     H,RSA
009A 220000    E   117         SHLD    POTFLG
009D 3E00          118         MVI     A,0
009F CD0000    E   119         CALL    DISPOT  ;SU = 0
00A2 3E01          120         MVI     A,1
00A4 CD0000    E   121         CALL    DISPOT  ;SL = 1
00A7 C34400    C   122         JMP     END40
                   123
                   124 ;READ SHOULDER UP POT
00AA 21AA00    C   125 RSU:    LXI     H,RSU
00AD 220000    E   126         SHLD    POTFLG
00B0 3E00          127         MVI     A,0
00B2 CD0000    E   128         CALL    DISPOT  ;SU = 0
00B5 C34400    C   129         JMP     END40
                   130
                   131 ;READ SHOULDER LEFT/RIGHT POT
00B8 21B800    C   132 RSL:    LXI     H,RSL
00BB 220000    E   133         SHLD    POTFLG
00BE 3E01          134         MVI     A,1
00C0 CD0000    E   135         CALL    DISPOT  ;SL = 1
00C3 C34400    C   136         JMP     END40
                   137
                   138
                   139 ;++++++++++++++++++++++++++++++++++++++++++++++++
                   140 ;READ WRIST POTENTIOMETER, WHICH ONE?
00C6 FE41          141 INPT43: CPI     'A'
00C8 CAD800    C   142         JZ      RWA
00CB FE55          143         CPI     'U'
00CD CAEB00    C   144         JZ      RWU
00D0 FE4C          145         CPI     'L'
00D2 CAF900    C   146         JZ      RWL
00D5 C30000    E   147         JMP     ERROR
                   148
                   149 ;READ ALL WRIST POTS:
00D8 21D800    C   150 RWA:    LXI     H,RWA
00DB 220000    E   151         SHLD    POTFLG
00DE 3E04          152         MVI     A,4
00E0 CD0000    E   153         CALL    DISPOT  ;WU = 4
00E3 3E05          154         MVI     A,5
00E5 CD0000    E   155         CALL    DISPOT  ;WL = 5
00E8 C34400    C   156         JMP     END40
                   157
                   158 ;READ WRIST UP/DOWN POT:
00EB 21EB00    C   159 RWU:    LXI     H,RWU
00EE 220000    E   160         SHLD    POTFLG
```

```
  LOC  OBJ          LINE        SOURCE STATEMENT

  00F1 3E04          161          MVI     A,4
  00F3 CD0000    E   162          CALL    DISPOT  ;WU = 4
  00F6 C34400    C   163          JMP     END40
                     164
                     165 ;READ WRIST LEFT/RIGHT POT:
  00F9 21F900    C   166 RWL:     LXI     H,RWL
  00FC 220000    E   167          SHLD    POTFLG
  00FF 3E05          168          MVI     A,5
  0101 CD0000    E   169          CALL    DISPOT  ;WL = 5
  0104 C34400    C   170          JMP     END40
                     171
                     172          END


PUBLIC SYMBOLS
RDPOT  C 0000

EXTERNAL SYMBOLS
DISPOT E 0000    ERROR  E 0000    EXIT   E 0000    OUTPUT E 0000
POTFLG E 0000    START1 E 0000

USER SYMBOLS
DISPOT E 0000    END40  C 0044    ERROR  E 0000    EXIT   E 0000
INPT40 C 000E    INPT41 C 0074    INPT42 C 0085    INPT43 C 00C6
LT1    A 000C    LT2    A 000A    OT1    D 0000    OT2    D 000C
OUTPUT E 0000    POTFLG E 0000    RALL   C 0025    RDPOT  C 0000
RELBOW C 005B    RSA    C 0097    RSHLDR C 004A    RSL    C 00B8
RSU    C 00AA    RWA    C 00D8    RWL    C 00F9    RWRIST C 0066
RWU    C 00EB    START1 E 0000    UPDATE C 0081

ASSEMBLY COMPLETE,  NO ERRORS
```

```
DISPOT   13     56     58     60     62     64     81    119    121
        128    135    153    155    162    169
END40    67#    82    122    129    136    156    163    170
ERROR    12     50     98    113    147
EXIT     12     38     68     75     89
INPT40   37     42#
INPT41   67     94#
INPT42   74    107#
INPT43   88    141#
LT1      22#    35
LT2      23#    72     86
OT1      19#    34
OT2      20#    71     85
OUTPUT   13     36     73     87
POTFLG   12     54     79    102    117    126    133    151    160
        167
RALL     43     53#    53
RDPOT    11     34#
RDPOTW    1
RELBOW   47     78#    78
RSA     108    116#   116
RSHLDR   45     71#
RSL     112    132#   132
RSU     110    125#   125
RWA     142    150#   150
RWL     146    166#   166
RWRIST   49     85#
RWU     144    159#   159
START1   12     97
UPDATE   95    102#
```

CROSS REFERENCE COMPLETE

```
ASM80 :F1:RELAYW.ASY XREF PAGEWIDTH(72) PRINT(:LP:)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         RELAYW   PAGE    1

  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    RELAYW
                       2
                       3 ;PROGRAMMER:  C.MORRIN
                       4 ;VERSION 1.0W
                       5 ;DATE OF LAST CHANGE:  NOVEMBER 3, 1977
                       6
                       7 ;************************************************
                       8
                       9 ;THESE ROUTINES START AND STOP THE RELAYS.
                      10 ;THE RSTART ENTRY POINT STARTS THE RELAY
                      11 ;INDICATED BY PRADD AND DIRFLG.
                      12 ;(THE FUNCTION TO BE OPERATED IS ENCODED IN BITS
                      13 ; 0,1,2 OF THE BYTE WHICH PRADD POINTS TO.)
                      14 ;(DIRFLG INDICATES WHICH OF THE TWO RELAYS USED
                      15 ;BY THAT FUNCTION IS TO BE TURNED ON.)
                      16 ;
                      17 ;RSTOP STOPS THE RELAY.
                      18
                      19 ;************************************************
                      20
                      21          CSEG
                      22
                      23          PUBLIC  RSTART,RSTOP
                      24          EXTRN   RELAY1,PRADD,DIRFLG,ERROR,WAIT
                      25
                      26 ;************************************************
                      27
0000 E5               28 RSTART:  PUSH    H
0001 C5               29          PUSH    B
0002 2A0000    E      30          LHLD    PRADD
0005 7E               31          MOV     A,M                 ;GET FUNCTION
0006 E60F             32          ANI     0FH
0008 CA3B00    C      33          JZ      SHLDUP
000B FE01             34          CPI     1
000D CA4100    C      35          JZ      SHLDLR
0010 FE02             36          CPI     2
0012 CA4700    C      37          JZ      ELBOWU
0015 FE03             38          CPI     3
0017 CA4D00    C      39          JZ      EXTND
001A FE04             40          CPI     4
001C CA5300    C      41          JZ      WRISTU
001F FE05             42          CPI     5
0021 CA5C00    C      43          JZ      WRISTL
0024 FE06             44          CPI     6
0026 CA5900    C      45          JZ      WRISTR
0029 FE08             46          CPI     8
002B CA6B00    C      47          JZ      HANDOP
002E FE09             48          CPI     9
0030 CA7100    C      49          JZ      HANDCL
0033 FE0E             50          CPI     0EH
0035 CA7700    C      51          JZ      XTEND
0038 C30000    E      52          JMP     ERROR
                      53
003B 010100           54 SHLDUP:  LXI     B,1
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

003E C37D00   C     55          JMP     RELYGO
0041 010102         56 SHLDLR: LXI     B,201H
0044 C37D00   C     57          JMP     RELYGO
0047 010200         58 ELBOWU: LXI     B,2
004A C37D00   C     59          JMP     RELYGO
004D 010300         60 EXTND:  LXI     B,3
0050 C37D00   C     61          JMP     RELYGO
0053 010104         62 WRISTU: LXI     B,401H
0056 C35700   C     63          JMP     R2
0059 C30000   E     64 WRISTR: JMP     ERROR
005C 010106         65 WRISTL: LXI     B,601H
005F 3A0000   E     66 R2:     LDA     DIRFLG
0062 E6FF           67          ANI     OFFH    ;SET ZERO FLAG
0064 C26600   C     68          JNZ     R1
0067 04             69          INR     B
0068 C36600   C     70          JMP     R1
006B 010202         71 HANDOP: LXI     B,202H
006E C36600   C     72          JMP     R1
0071 010203         73 HANDCL: LXI     B,302H
0074 C36600   C     74          JMP     R1
0077 010300         75 XTEND:  LXI     B,3
007A C36600   C     76          JMP     R1
                    77
007D 3A0000   E     78 RELYGO: LDA     DIRFLG
0080 E6FF           79          ANI     OFFH    ;SET ZERO FLAG
0082 CA8600   C     80          JZ      R1
                    81 ;CHANGE FROM UP (LEFT) TO DOWN (RIGHT):
0085 04             82          INR     B
0086 78             83 R1:     MOV     A,B
0087 320100   E     84          STA     RELAY1+1        ;SELECT FUNCTION
008A C5             85          PUSH    B
008B 01D007         86          LXI     B,2000
008E CD0000   E     87          CALL    WAIT    ;WAIT .1 SEC
0091 C1             88          POP     B
0092 79             89          MOV     A,C
0093 320200   E     90          STA     RELAY1+2 ;START RELAY(S)
0096 C1             91          POP     B
0097 E1             92          POP     H
0098 C9             93          RET
                    94
                    95 ;************************************************
                    96
0099 3E00           97 RSTOP:  MVI     A,0
009B 320200   E     98          STA     RELAY1+2
009E C9             99          RET
                   100
                   101          END


PUBLIC SYMBOLS
RSTART C 0000    RSTOP  C 0099

EXTERNAL SYMBOLS
DIRFLG E 0000    ERROR  E 0000    PRADD  E 0000    RELAY1 E 0000
WAIT   E 0000
```

USER SYMBOLS

DIRFLG	E 0000	ELBOWU	C 0047	ERROR	E 0000	EXTND	C 004[illegible]
HANDCL	C 0071	HANDOP	C 006B	PRADD	E 0000	R1	C 008[illegible]
R2	C 005F	RELAY1	E 0000	RELYGO	C 007D	RSTART	C 0000
RSTOP	C 0099	SHLDLR	C 0041	SHLDUP	C 003B	WAIT	E 0000
WRISTL	C 005C	WRISTR	C 0059	WRISTU	C 0053	XTEND	C 0077

ASSEMBLY COMPLETE, NO ERRORS

```
DIRFLG    24      66      78
ELBOWU    37      58#
ERROR     24      52      64
EXTND     39      60'
HANDCL    49      73#
HANDOP    47      71#
PRADD     24      30
R1        68      70      72      74      76      80      83#
R2        63      66#
RELAYI    24      84      90      98
RELAYW     1
RELYGO    55      57      59      61      78#
RSTART    23      28#
RSTOP     23      97#
SHLDLR    35      56#
SHLDUP    33      54#
WAIT      24      87
WRISTL    43      65#
WRISTR    45      64#
WRISTU    41      62#
XTEND     51      75#

CROSS REFERENCE COMPLETE
```

```
ASM80 :F1:TRANS.ASY XREF PAGEWIDTH(72)


ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0         TRANS    PAGE    1

  LOC  OBJ          LINE        SOURCE STATEMENT

                       1          NAME    TRANS
                       2
                       3 ;PROGRAMMER:  C.MORRIN
                       4 ;VERSION 2.0
                       5 ;DATE OF LAST CHANGE:  NOVEMBER 4, 1977
                       6
                       7 ;*************************************************
                       8
                       9          CSEG
                      10
                      11          PUBLIC  TRANS0
                      12          EXTRN   OUTPUT,PRADD,TAD,DPROGM
                      13          EXTRN   ASCHEX,ASCHX1,EXIT,PRG11B
                      14          EXTRN   XMIT,PROMT,STOPFG
                      15
                      16 ;*************************************************
                      17
                      18 ;OUTPUT MESSAGE TABLE:
                      19          DSEG
                      20
0000 20235354         21 OTRAN1: DB       ' #STEPS='
0004 4550533D
0008 20545241         22 OTRAN2: DB       ' TRANSFER FROM '
000C 4E534645
0010 52204652
0014 4F4D20
                      23
0008                  24 LTRAN1  EQU      8
000F                  25 LTRAN2  EQU      15
                      26
                      27 ;*************************************************
                      28
                      29 ;PROGRAM TRANSFER ROUTINE (CALLED BY PROGRM)
                      30
                      31 ;PROGRAM TRANSFER MODE:
0017 3EF1             32 TRANS0: MVI      A,0F1H
0019 320100    E      33          STA      TAD+1
001C 210800    D      34          LXI      H,OTRAN2
001F 0E0F             35          MVI      C,LTRAN2
0021 CD0000    E      36          CALL     OUTPUT  ;' TRANSFER FROM '
0024 212A00    D      37          LXI      H,TRANS1
0027 C30000    E      38          JMP      EXIT
                      39
                      40 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                      41 ;PROGRAM TRANSFER MODE, FIRST ADDRESS DIGIT
002A FE2A             42 TRANS1: CPI      '*'
002C CA3B00    D      43          JZ       TRANS2
002F CD0000    E      44          CALL     ASCHX1
0032 320000    E      45          STA      TAD
0035 214400    D      46          LXI      H,TRANS3
0038 C30000    E      47          JMP      EXIT
                      48
                      49 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                      50 ;PROGRAM TRANSFER MODE, HARDWIRED MEMORY
```

```
LOC  OBJ          LINE        SOURCE STATEMENT

0038 CD0000   E     51 TRANS2: CALL     XMIT     ;('*')
003E 21B400   D     52         LXI      H,TRANS5
0041 C30000   E     53         JMP      EXIT
                    54
                    55 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    56 ;PROGRAM TRANSFER MODE, 2ND ADDRESS DIGIT
0044 CD0000   E     57 TRANS3: CALL     ASCHEX
0047 210000   E     58         LXI      H,TAD
004A B6             59         ORA      M
004B 77             60         MOV      M,A
004C 210000   D     61 T3:     LXI      H,OTRAN1
004F 0E08           62         MVI      C,LTRAN1
0051 CD0000   E     63         CALL     OUTPUT   ;' #STEPS='
0054 215A00   D     64         LXI      H,TRANS4
0057 C30000   E     65         JMP      EXIT
                    66
                    67 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                    68 ;PROGRAM TRANSFER MODE, # OF STEPS
005A CD0000   E     69 TRANS4: CALL     ASCHEX
005D 4F             70         MOV      C,A
005E 2A0000   E     71         LHLD     TAD
0061 EB             72         XCHG
0062 2A0000   E     73         LHLD     PRADD
                    74 ;READY TO TRANSFER PROGRAM:
0065 0604           75 TRAN2:  MVI      B,4
0067 1A             76 TRAN1:  LDAX     D
0068 77             77         MOV      M,A
0069 13             78         INX      D
006A 23             79         INX      H
006B 05             80         DCR      B
006C C26700   D     81         JNZ      TRAN1
006F CD0000   E     82         CALL     DPROGM
0072 3A0000   E     83         LDA      STOPFG
0075 E6FF           84         ANI      OFFH     ;SET ZERO FLAG
0077 C20000   E     85         JNZ      PRG11B
                    86 ;RETURN IF LAST STEP WAS A "STOP" FLAG
007A 220000   E     87         SHLD     PRADD
007D 0D             88         DCR      C
007E C26500   D     89         JNZ      TRAN2
0081 C30000   E     90         JMP      PRG11B
                    91
                    92 ;+++++++++++++++++++++++++++++++++++++++++++++++++
                       +
                    93 ;HARDWIRED MEMORY, 2ND ADDRESS DIGIT:
0084 CD0000   E     94 TRANS5: CALL     ASCHEX
0087 07             95         RLC
0088 5F             96         MOV      E,A
0089 1600           97         MVI      D,0
008B 210000   E     98         LXI      H,PROMT
008E 19             99         DAD      D
                   100 ;(REG H) = POINTER TO HARDWIRED PROGRAM
008F 7E            101         MOV      A,M
0090 320000   E    102         STA      TAD
0093 23            103         INX      H
0094 7E            104         MOV      A,M
```

```
ISIS-II 8080/8085 MACRO ASSEMBLER, V4.0        TRANS    PAGE    3


  LOC  OBJ          LINE        SOURCE STATEMENT

  0095 320100   E    105          STA     TAD+1
  0098 C34C00   D    106          JMP     T3
                     107
                     108          END


PUBLIC SYMBOLS
TRANS0 D 0017

EXTERNAL SYMBOLS
ASCHEX E 0000    ASCHX1 E 0000    DPROGM E 0000    EXIT   E 0000
OUTPUT E 0000    PRADD  E 0000    PRG11B E 0000    PROMT  E 0000
STOPFG E 0000    TAD    E 0000    XMIT   E 0000

USER SYMBOLS
ASCHEX E 0000    ASCHX1 E 0000    DPROGM E 0000    EXIT   E 0000
LTRAN1 A 0008    LTRAN2 A 000F    OTRAN1 D 0000    OTRAN2 D 0008
OUTPUT E 0000    PRADD  E 0000    PRG11B E 0000    PROMT  E 0000
STOPFG E 0000    T3     D 004C    TAD    E 0000    TRAN1  D 0067
TRAN2  D 0065    TRANS0 D 0017    TRANS1 D 002A    TRANS2 D 003B
TRANS3 D 0044    TRANS4 D 005A    TRANS5 D 0084    XMIT   E 0000

ASSEMBLY COMPLETE,   NO ERRORS
```

```
ASCHEX    13      57      69      94
ASCHX1    13      44
DPROGM    12      82
EXIT      13      38      47      53      65
LTRAN1    24#     62
LTRAN2    25#     35
OTRAN1    21#     61
OTRAN2    22#     34
OUTPUT    12      36      63
PRADD     12      73      87
PRG11B    13      85      90
PROMT     14      98
STOPFG    14      83
T3        61#    106
TAD       12      33      45      58      71      102     105
TRAN1     76#     81
TRAN2     75#     89
TRANS      1
TRANS0    11      32#
TRANS1    37      42#
TRANS2    43      51#
TRANS3    46      57#
TRANS4    64      69#
TRANS5    52      94#
XMIT      14      51

CROSS REFERENCE COMPLETE
```

APPENDIX C: MODEL OF MANIPULATOR PROGRAMMER ACCURACY

REQUIRED ACCURACY

Level 1: Overall system accuracy is assumed to be a circle with diameter 0.5 inch.

Level 2: The system is divided into five functions, each of which has the same accuracy expressed in percent. The contribution of each function to the overall system accuracy is proportional to the distance between the function's sensor and the work area. The five functions are shoulder up/down (SU), shoulder left/right (SL), elbow up/down (EU), wrist up/down (WU), and wrist left/right (WL).

Assume that the distance between the sensor and the work area is fixed as follows:

Shoulder to work area = 6 feet
Elbow to work area = 4 feet
Wrist to work area = 2 feet

Case 2A

Assume that the errors are Gaussian and independent. Then the variance of the system error equals the sum of the variance of the subsystem errors.

$$\text{system error} = [(\text{SU error})^2 + (\text{SL error})^2 + (\text{EU error})^2 + (\text{WU error})^2 + (\text{WL error})^2]^{1/2}.$$

$$\text{SU error} = (6 \text{ feet})\ (2\pi)\ (270°/360°) \times \text{channel accuracy}$$
$$= 9\pi \text{ feet} \times \text{channel accuracy}$$
$$= 28.2 \text{ feet} \times \text{channel accuracy}$$

Similarly,

SL error = 28.2 feet X channel accuracy
EU error = 16.7 feet X channel accuracy
WU error = 8.4 feet X channel accuracy
WL error = 8.4 feet X channel accuracy

Hence system error = 0.5 inch = 600 inches X channel accuracy. Therefore, channel accuracy = 1 part per 1200 = 800 ppm. Channel accuracy includes both data acquisition errors and hydraulic system consistency.

Case 2B

Assume that the errors are dependent. For example, the temperature-related errors will probably change as a group.

$$\text{system error} = [(\text{SU error} + \text{EU error} + \text{WU error})^2 + (\text{SL error} + \text{WL error})^2]^{1/2}.$$

Since movements in the same direction are correlated (possibly canceling under some circumstances), orthogonal movements will follow the Pythagorean theorem.

system error = 0.5 inch = 710 inches X channel accuracy.

Hence channel accuracy = 1 part per 1420 parts = 700 ppm. Note that the difference between independent and dependent errors is small. Channel accuracy must be between 700 and 800 ppm.

PRELIMINARY ACCURACY ANALYSIS PREDICTED ON THE BASIS OF THE DESIGN

The data acquisition system has four major components:

Sensor (potentiometer)
Multiplexer
Precision voltage reference
Analog-to-digital converter

Potentiometers

The potentiometers are used as voltage dividers. The output of the potentiometers is connected to a 100-MΩ buffer amplifier; hence the current flowing through the potentiometers is constant.

The potentiometer should not be sensitive to temperature fluctuations, since any resistance change should be self-cancelling. But a potential problem with the potentiometers is a flat spot — where the resistance does not change. It is hoped that the solution to this problem is to use conductive plastic potentiometers and an extremely high resolution A/D converter; if we can measure the potentiometer voltage with much higher resolution than the nominal requirement, then it may be possible to divide the flat spots into distinguishable points.

Multiplexer Subsystem

The multiplexer includes two levels of MOS switches and two levels of instrumentation amplifier buffering. The switches have an impedance of 1 kΩ. The large changes in this impedance will be rendered insignificant by the 100-MΩ input resistance of the instrumentation amplifiers. The leakage currents in the switches will not impact the accuracy.

The instrumentation amplifiers have an input and output offset, which will not impact accuracy as long as it is constant. The input offset temperature coefficient is 10 μV/°C, and the output offset temperature coefficient is 15 μV/°C. Since the signal is 20 V, the total offset temperature coefficient is 1.25 ppm/°C. A specification for drift was not available. The noise figure is 20 μV, or 1 ppm. The power supply provides 0.15% regulation, and the amplifier reduces this to 2.5 mV of noise per volt of ripple. Since the

power requirement is 30 V, the ripple noise is 100 μV, or 5 ppm, for the 20-V signal.

Voltage Reference Subsystem

The voltage reference subsystem contains two voltage references (+10.000 and -10.000 V) and two current amplifiers. (The latter were required for the linkage manipulator pots and could be removed for the WSP pots.)

The voltage references have a temperature coefficient of 5 ppm and a drift of 50 ppm per year. Other specs include a noise figure of 5 ppm and a power-supply ripple of 4.5 ppm.

The current amplifier specs have not been calculated, since the components used are inexpensive and contain few specs. The current amplifiers are not required and will be removed if they are suspect.

Analog-to-Digital Converter Subsystem

The A/D converter has a temperature coefficient of 2.5 ppm/°C and a quantization noise figure of 16 ppm.

Summary of Noise Sources

	Noise Error, ppm	Temp Error, ppm	Drift Error, ppm/year
Voltage ref			
Temp coef		200 (20°)	
Drift			100 (max)
Noise	10		
Power supply	9		
Multiplexer			
Temp coef		50 (20°)	
Power supply	10		
Noise	2		
A/D converter			
Temp coef		50 (20°)	
Quantization	16		
Total	21*	300**	100

* Square root of sum of squares, since sources are independent.
**Simple sum, since temperature is dependent.

The predictable system errors are at least a factor of 2 better than the requirement. This analysis did not include noise from electromagnetic radiation, which was the predominant source of noise in the test. Self-noise appeared to be less than 500 ppm.

RESULTS FROM TESTING

As mentioned under test results, the measured accuracy was 800 ppm (circle of 0.5-inch diameter). This was attributed to an additional error source — electromagnetic interference from the low-pressure hydraulic pump. When this pump was off, the system noise was less than 200 ppm.


ATE
LME